EXHIBIT A

US008920332B2

(12) **United States Patent**
Hong et al.

(10) **Patent No.: US 8,920,332 B2**
(45) **Date of Patent: Dec. 30, 2014**

(54) **WEARABLE HEART RATE MONITOR**

(71) Applicant: **Fitbit, Inc.**, San Francisco, CA (US)

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(73) Assignee: **Fitbit, Inc.**, San Francisco, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/295,144**

(22) Filed: **Jun. 3, 2014**

(65) **Prior Publication Data**

US 2014/0288390 A1 Sep. 25, 2014

Related U.S. Application Data

(63) Continuation of application No. 14/292,669, filed on May 30, 2014, which is a continuation-in-part of application No. 13/924,784, filed on Jun. 24, 2013.

(60) Provisional application No. 61/662,961, filed on Jun. 22, 2012, provisional application No. 61/752,826, filed on Jan. 15, 2013, provisional application No. 61/830,600, filed on Jun. 3, 2013, provisional application No. 61/946,439, filed on Feb. 28, 2014, provisional application No. 61/955,045, filed on Mar. 18, 2014, provisional application No. 61/973,614, filed on Apr. 1, 2014, provisional application No. 62/001,624, filed on May 21, 2014, provisional application No. 62/001,585, filed on May 21, 2014.

(51) **Int. Cl.**

A61B 5/02	(2006.01)
A61B 5/024	(2006.01)
A61B 5/11	(2006.01)
A61B 5/0205	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 5/02427*** (2013.01); ***A61B 5/11*** (2013.01); ***A61B 5/0205*** (2013.01)

USPC **600/500**; 600/481; 600/483; 600/309; 600/310

(58) **Field of Classification Search**

USPC 600/301, 310, 481, 483, 500, 502, 503

See application file for complete search history.

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(Continued)

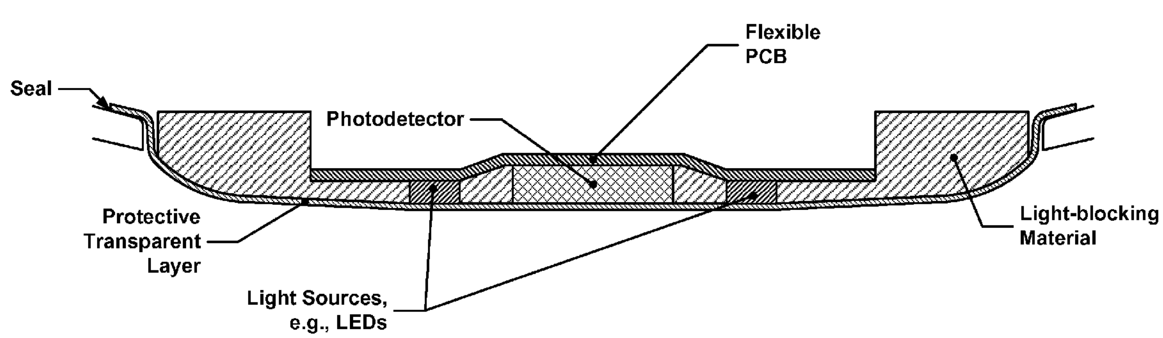
Primary Examiner — Michael D'Angelo

(74) *Attorney, Agent, or Firm* — Weaver Austin Villeneuve & Sampson LLP

(57) **ABSTRACT**

Some embodiments provide a wearable fitness monitoring device including a motion sensor and a photoplethysmographic (PPG) sensor. The PPG sensor includes (i) a periodic light source, (ii) a photo detector, and (iii) circuitry determining a user's heart rate from an output of the photo detector. Some embodiments provide methods for operating a heart rate monitor of a wearable fitness monitoring device to measure one or more characteristics of a heartbeat waveform. Some embodiments provide methods for operating the wearable fitness monitoring device in a low power state when the device determines that the device is not worn by a user. Some embodiments provide methods for operating the wearable fitness monitoring device in a normal power state when the device determines that the device is worn by a user.

30 Claims, 36 Drawing Sheets



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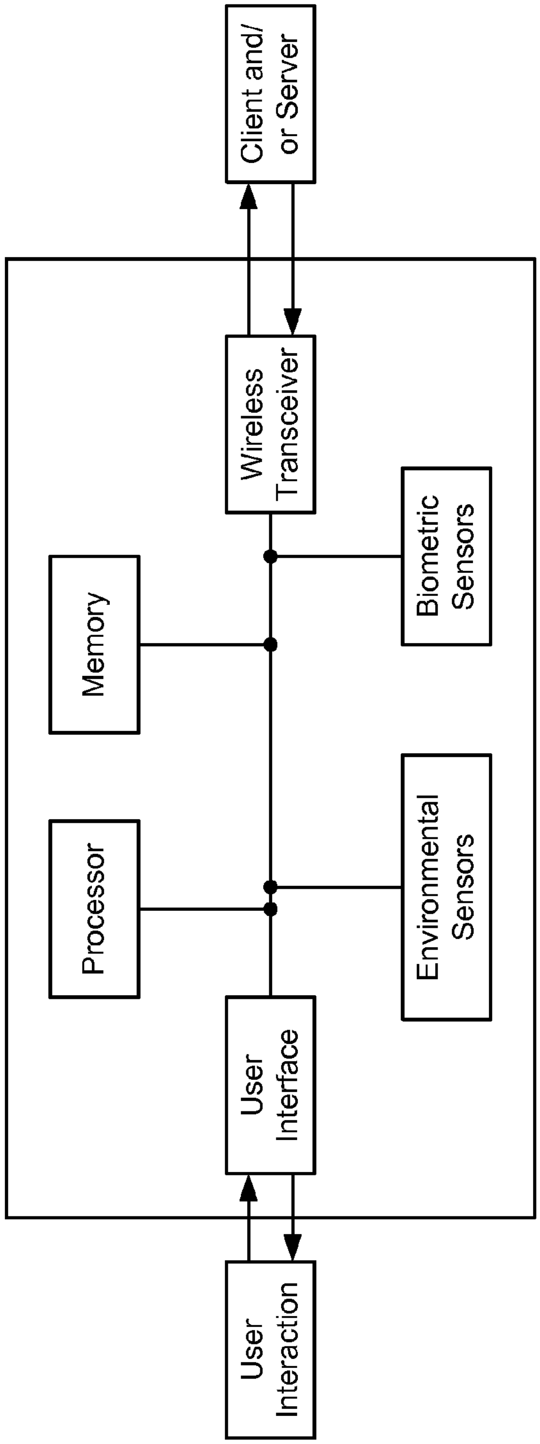

Client and/ or Server
Wireless Transceiver
Memory
Biometric Sensors
Processor
Environmental Sensors
User Interface
User Interaction

Figure 1

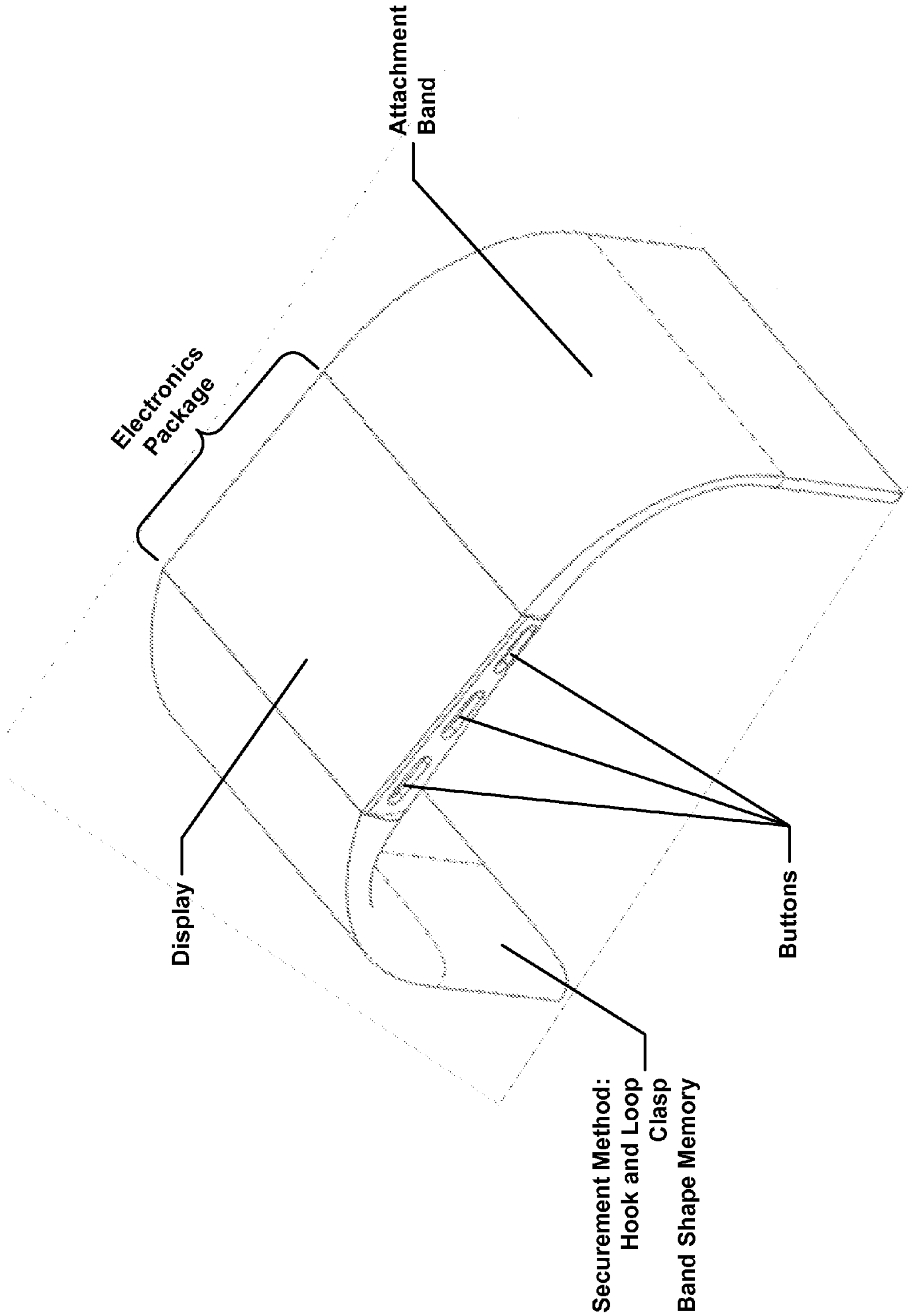

Attachment Band
Electronics Package
Display
Buttons
Securement Method:
Hook and Loop
Clasp
Band Shape Memory

Figure 2A

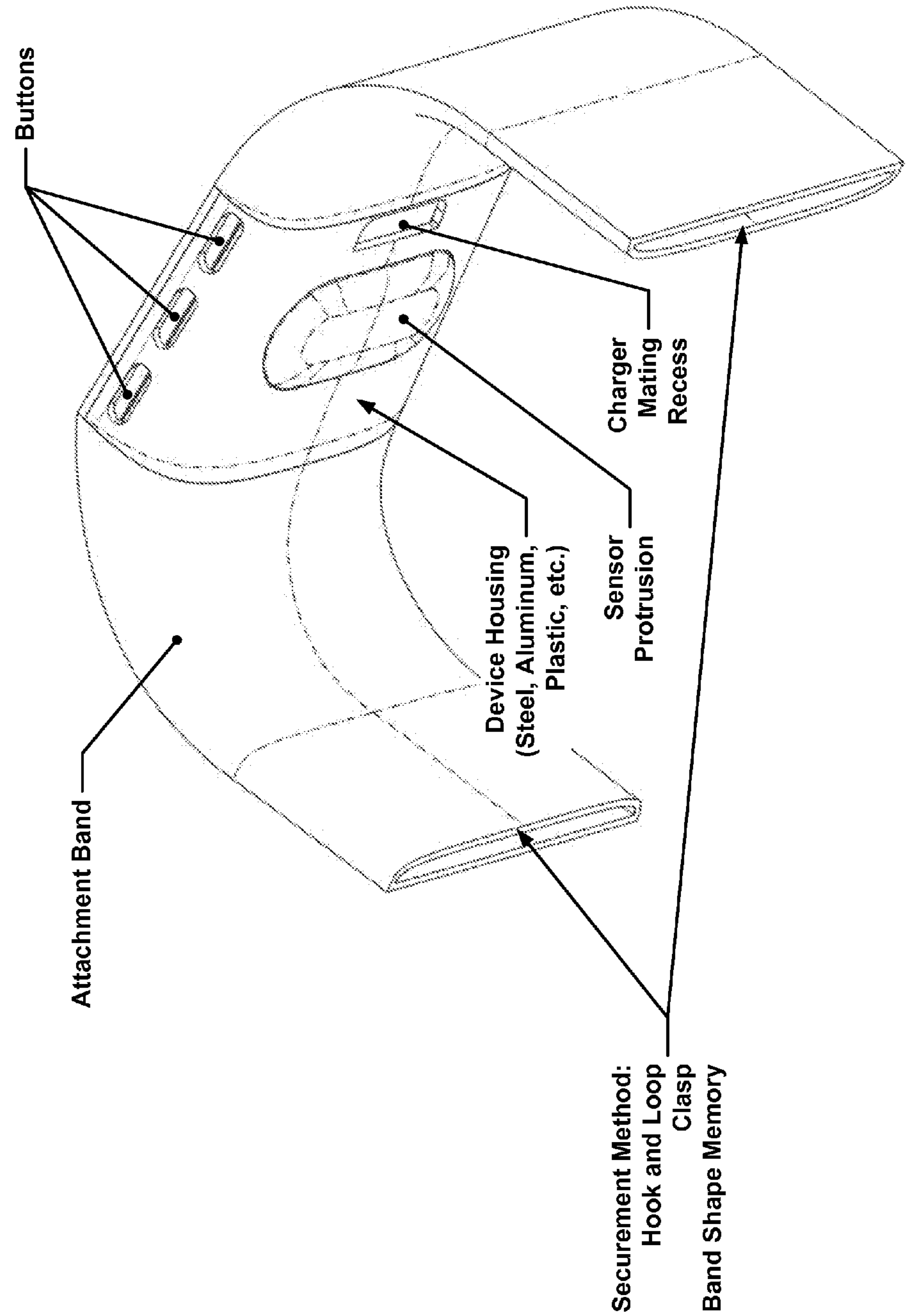

Buttons
Charger Mating Recess
Sensor Protrusion
Device Housing (Steel, Aluminum, Plastic, etc.)
Attachment Band
Securement Method:
Hook and Loop
Clasp
Band Shape Memory

Figure 2B

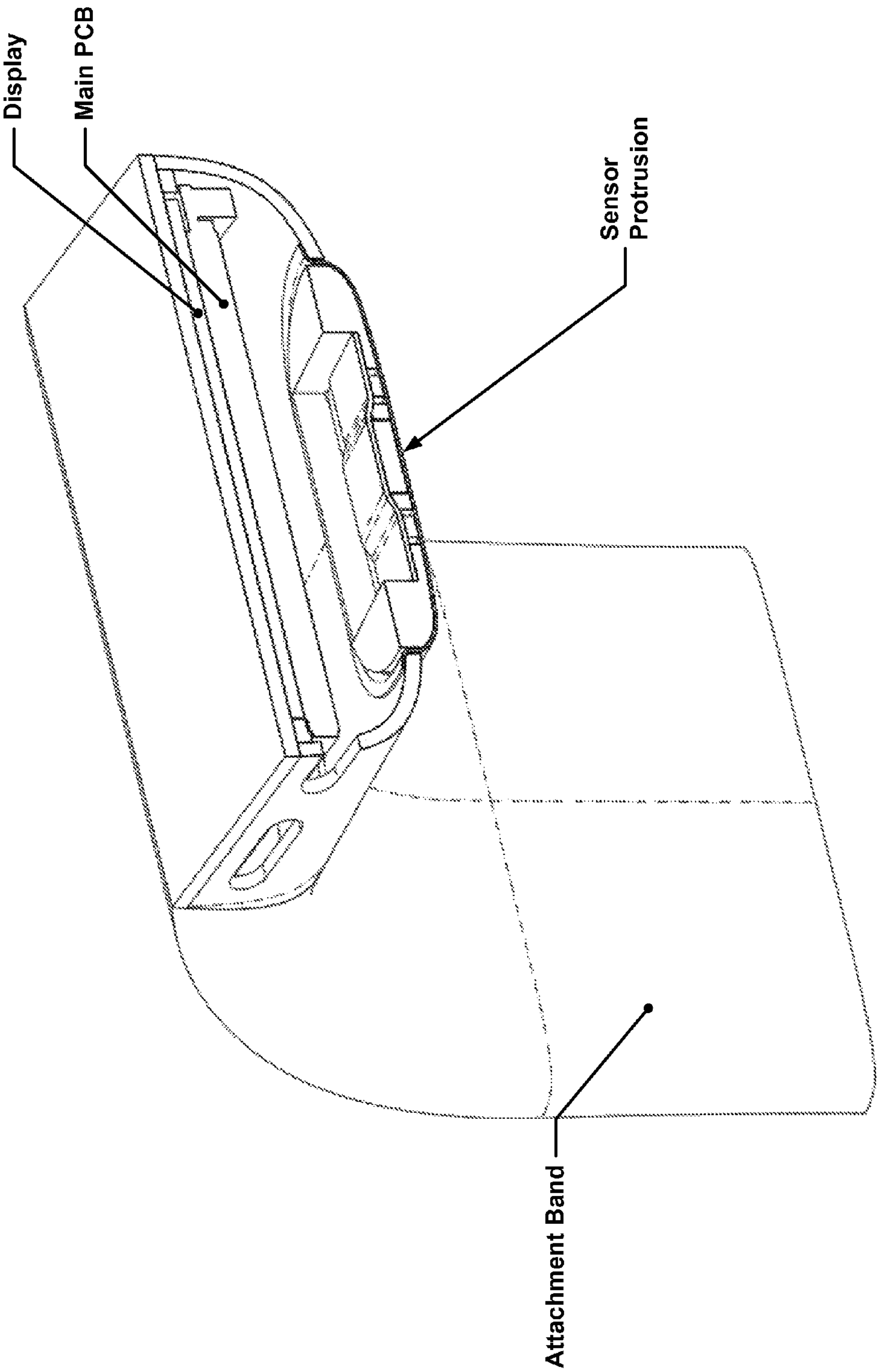


Figure 2C

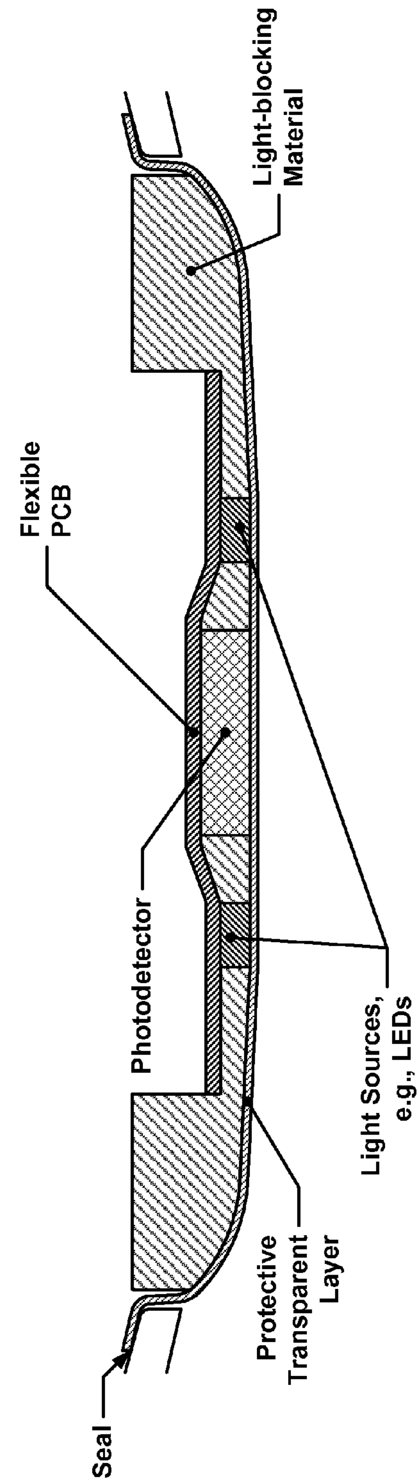


Figure 3A

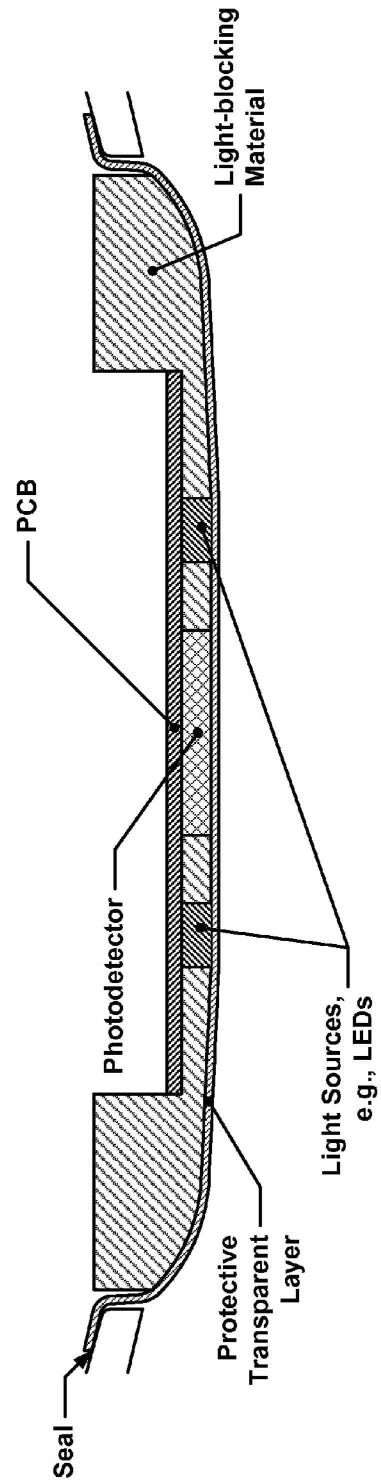
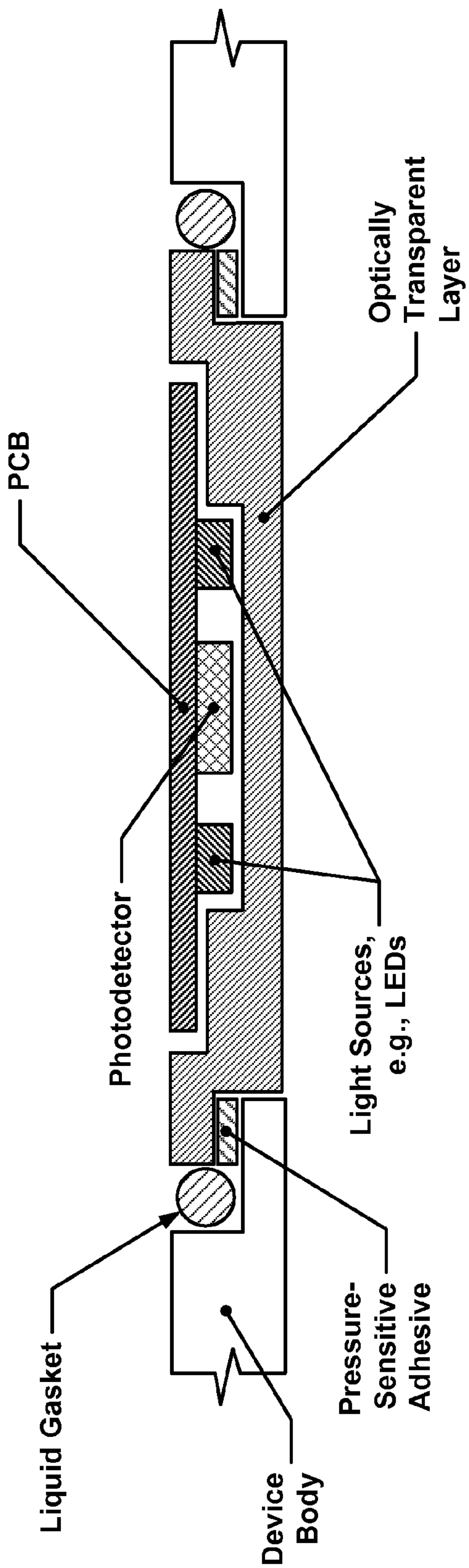


Figure 3B



PCB
Optically Transparent Layer
Photodetector
Light Sources, e.g., LEDs
Liquid Gasket
Device Body
Pressure-Sensitive Adhesive

Figure 3C

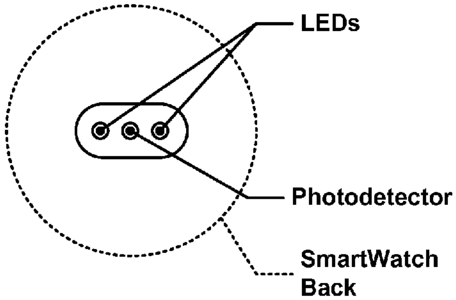


Figure 4A

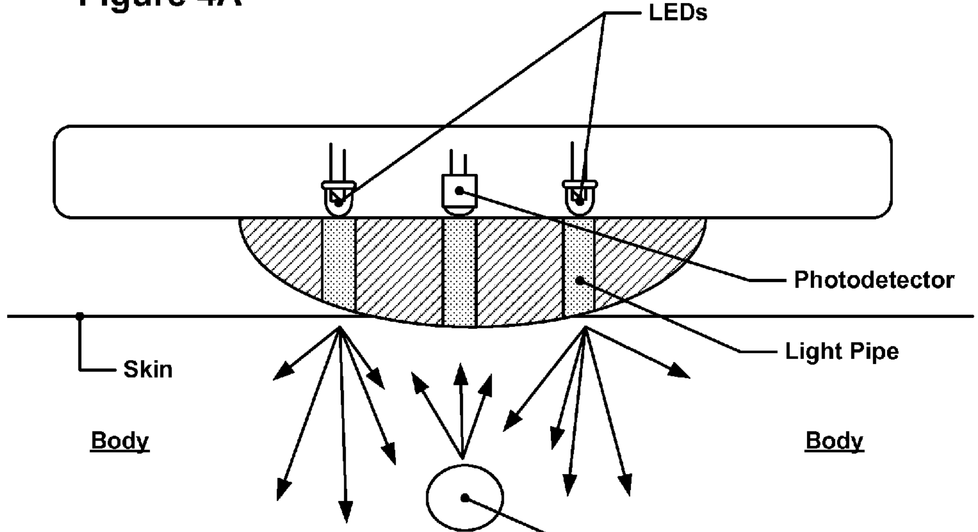


Figure 4B

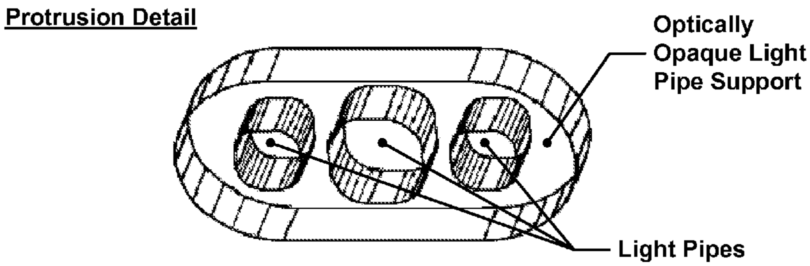


Figure 4C

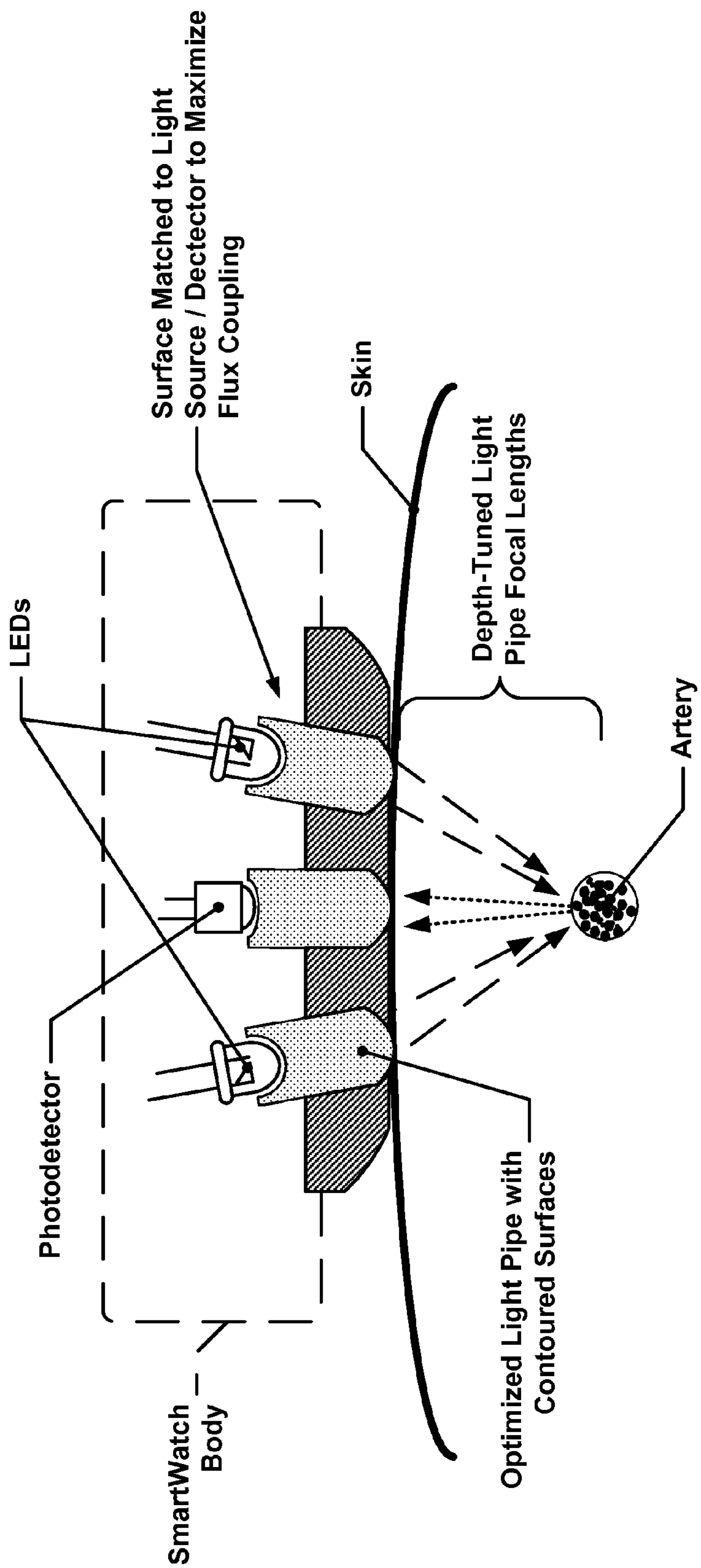

Surface Matched to Light Source / Dectector to Maximize Flux Coupling
LEDs
Skin
Depth-Tuned Light Pipe Focal Lengths
Artery
Photodetector
SmartWatch Body
Optimized Light Pipe with Contoured Surfaces

Figure 5

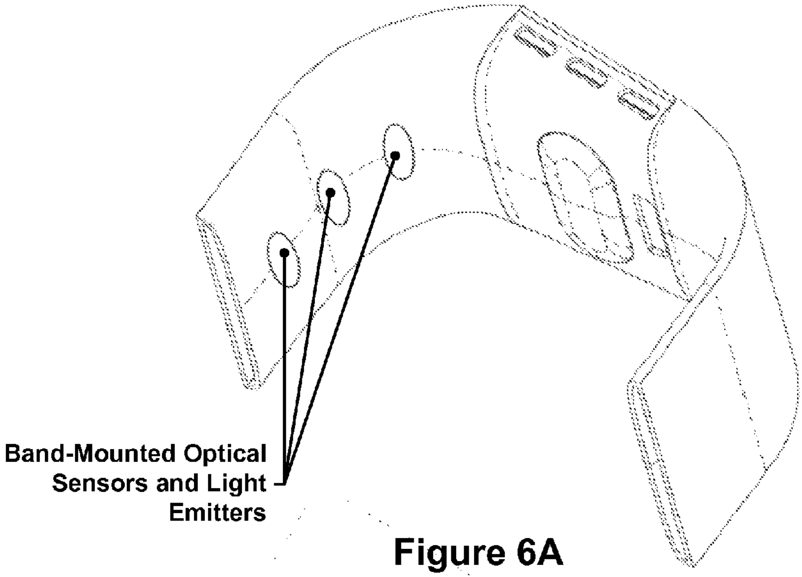


Figure 6A

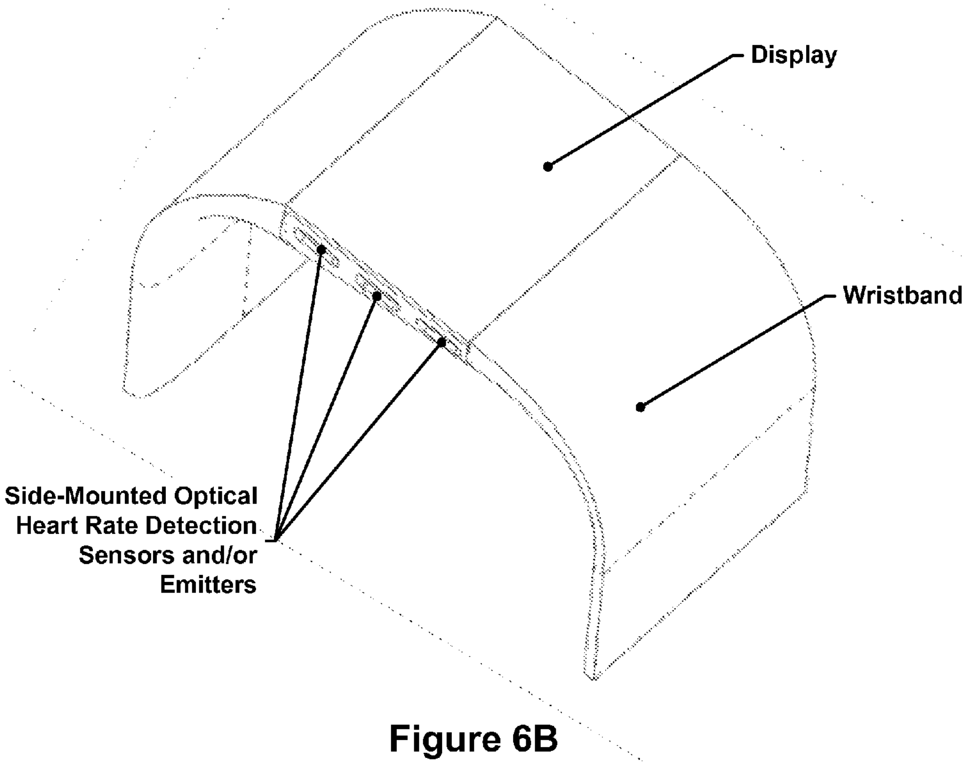


Figure 6B

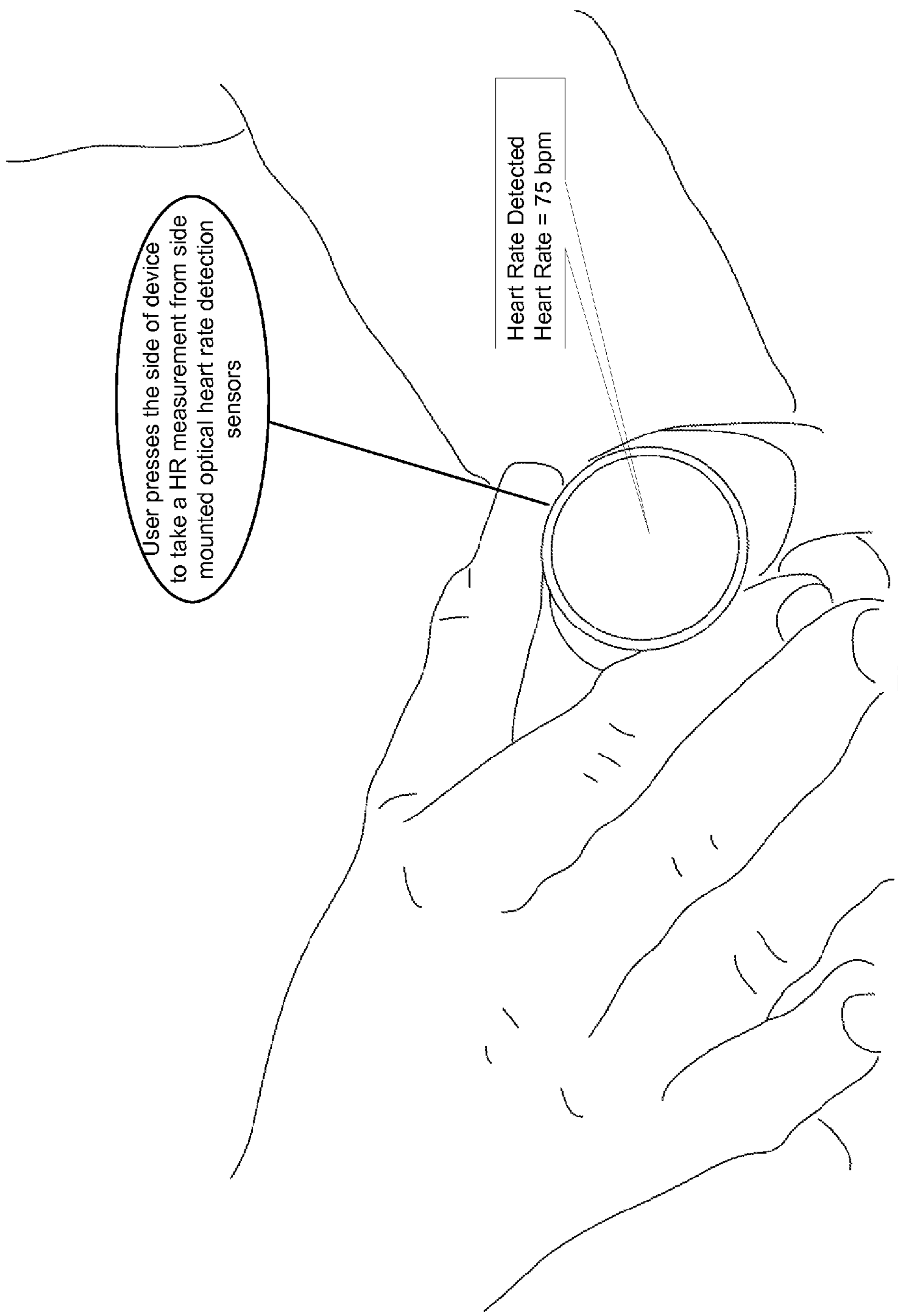

User presses the side of device to take a HR measurement from side mounted optical heart rate detection sensors
Heart Rate Detected
Heart Rate = 75 bpm

Figure 7

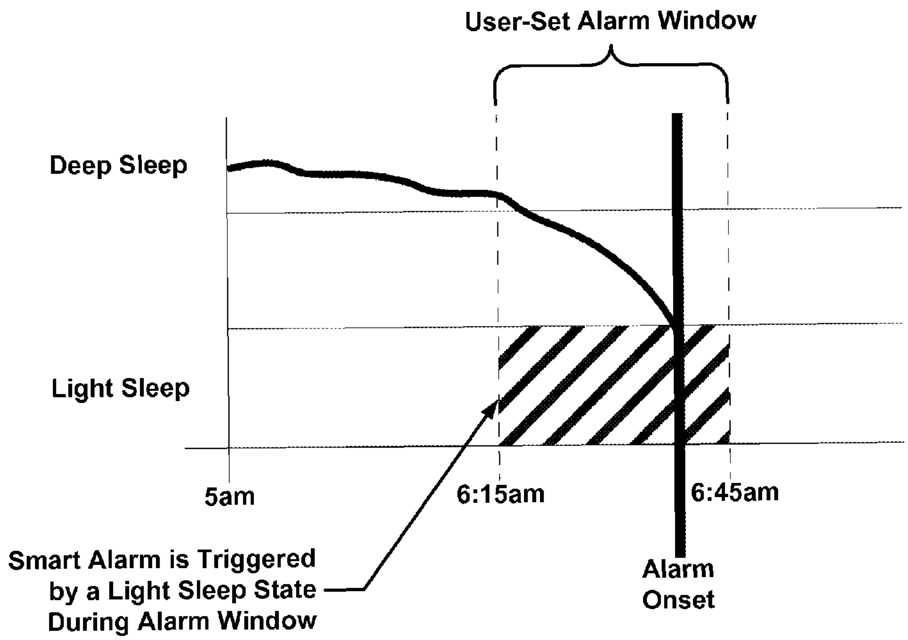


Figure 8

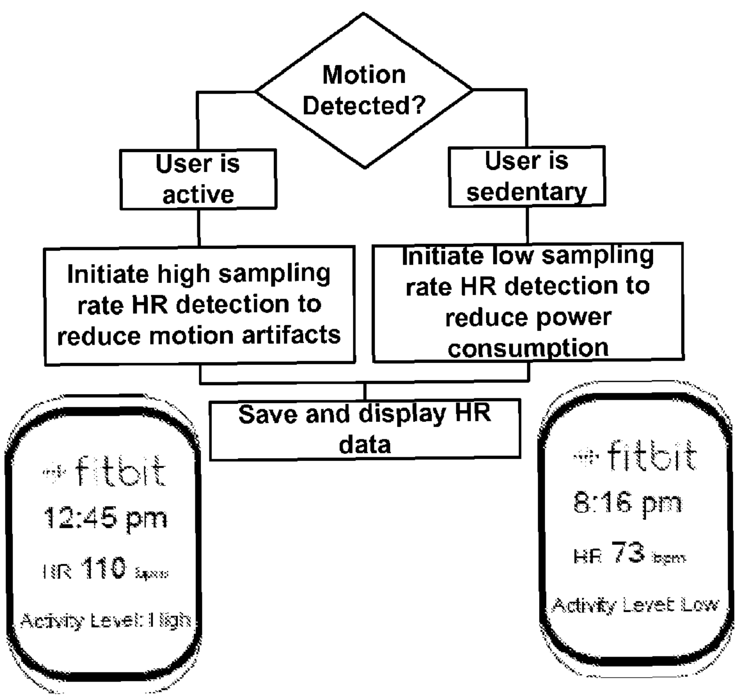


Figure 9

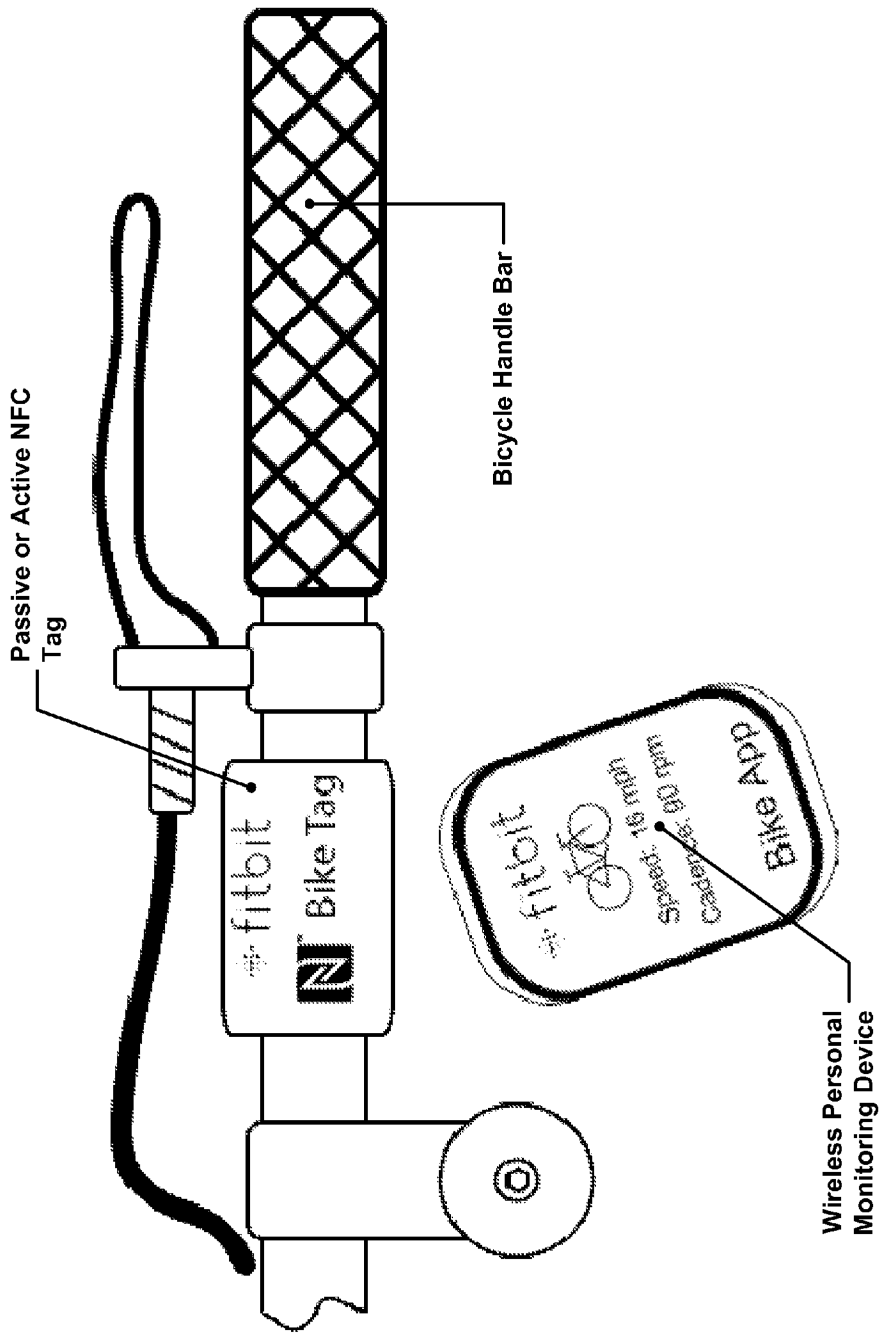

Passive or Active NFC Tag
Bicycle Handle Bar
fitbit
Bike Tag
fitbit
Speed: 16 mph
Cadence: 90 rpm
Bike App
Wireless Personal Monitoring Device

Figure 10

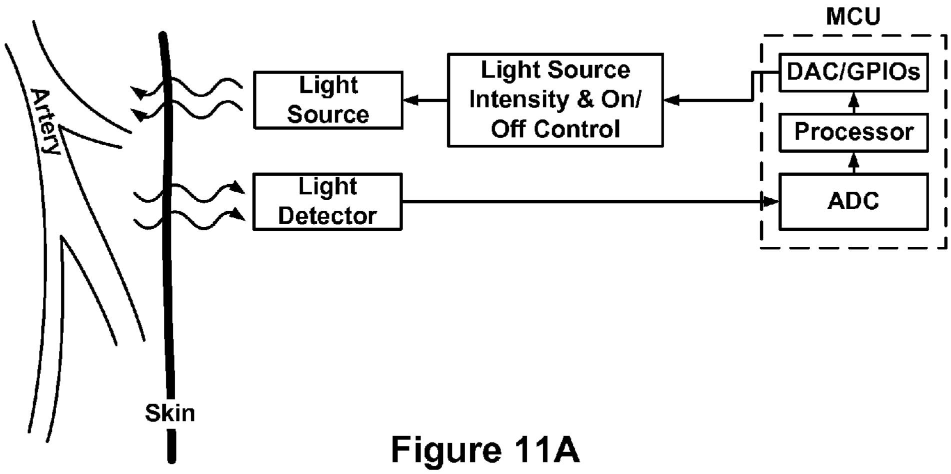


Figure 11A

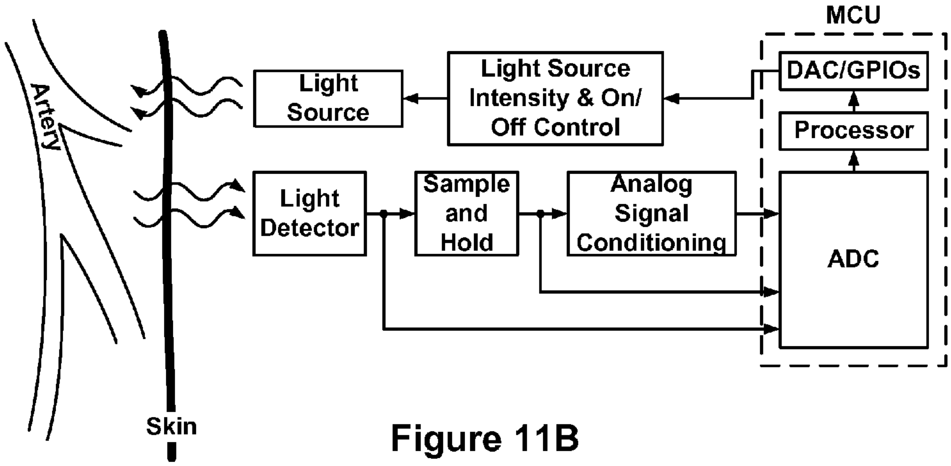


Figure 11B

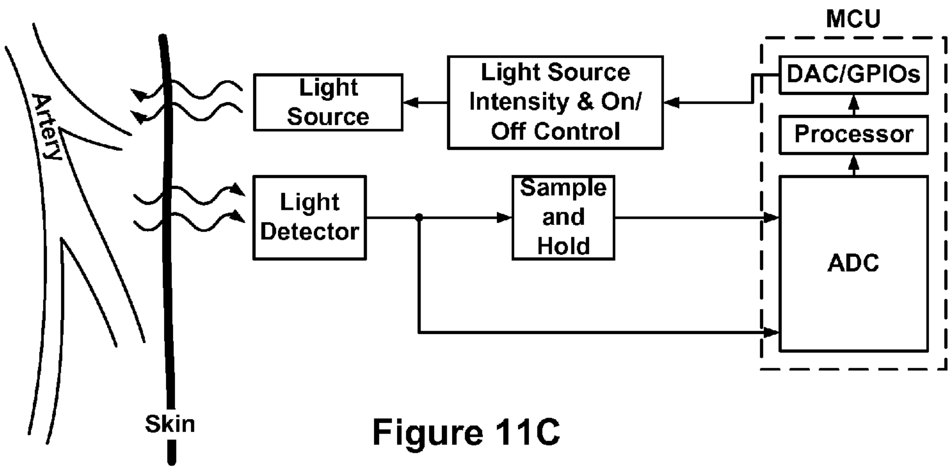


Figure 11C

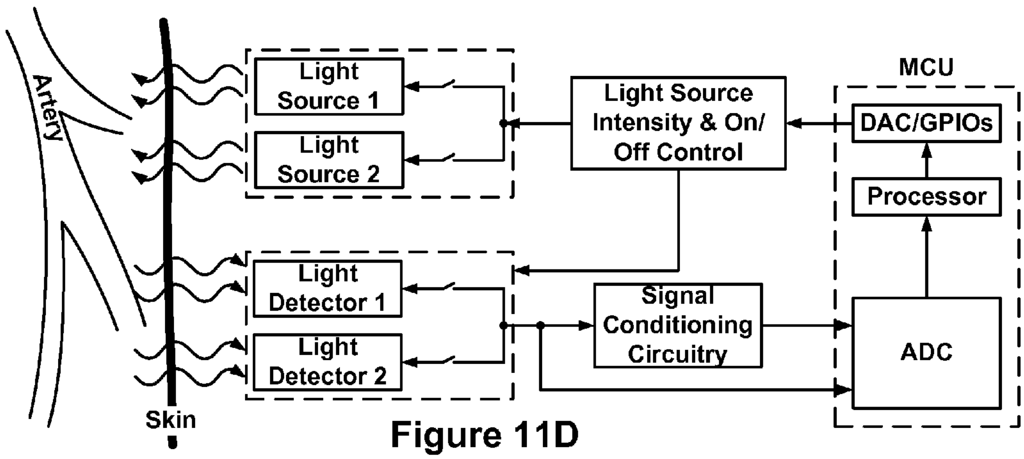


Figure 11D

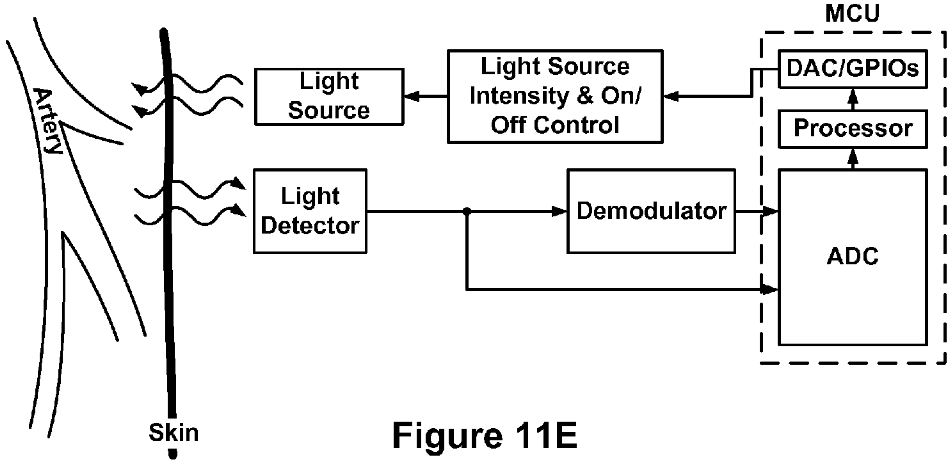


Figure 11E

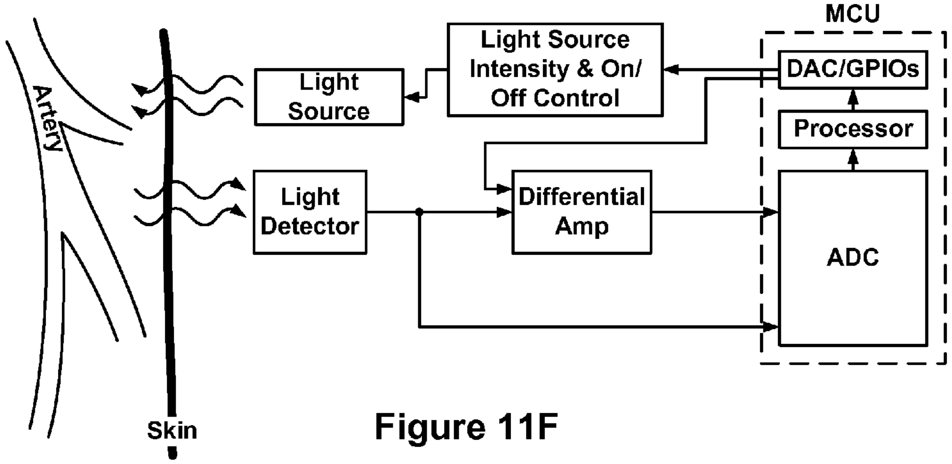


Figure 11F

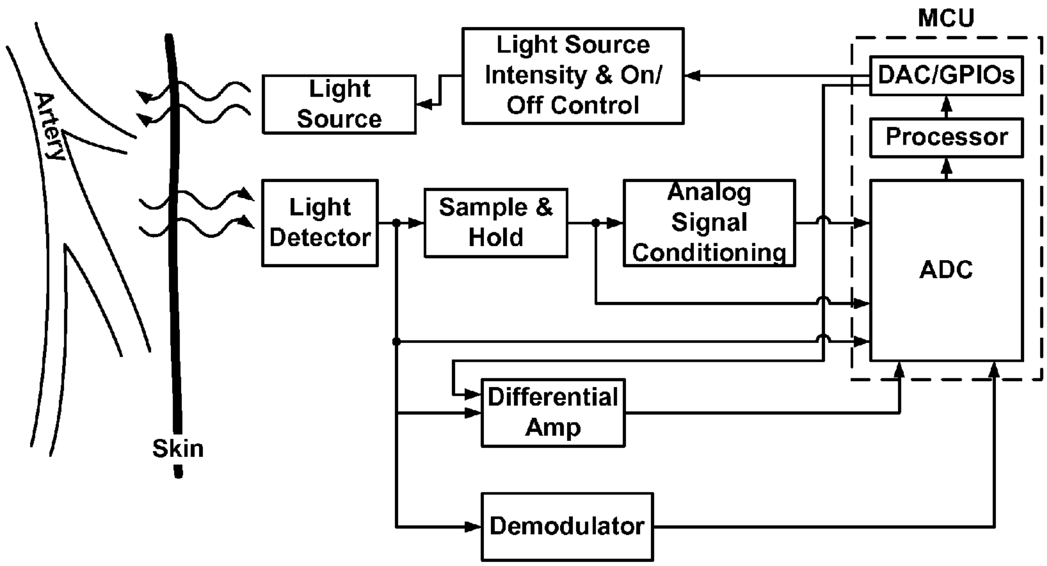

MCU
Light Source Intensity & On/ Off Control
DAC/GPIOs
Light Source
Processor
Artery
Light Detector
Sample & Hold
Analog Signal Conditioning
ADC
Differential Amp
Skin
Demodulator

Figure 11G

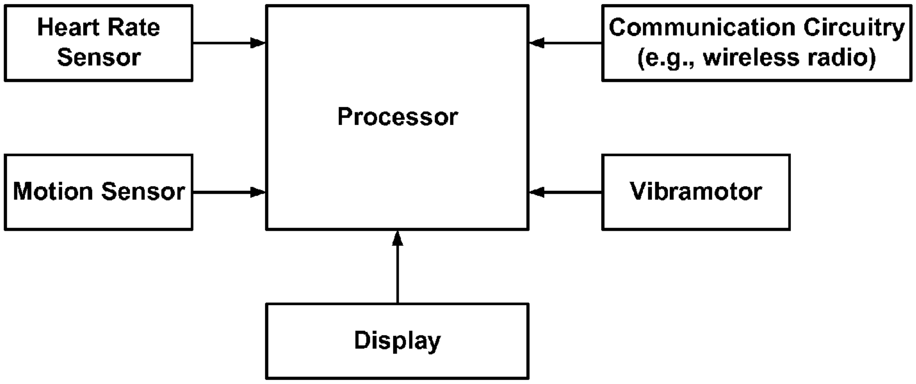


Figure 12A

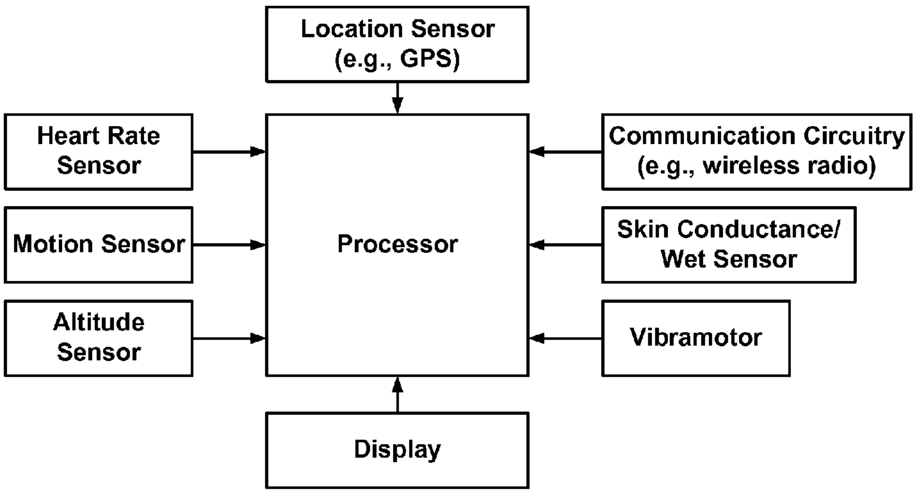


Figure 12B

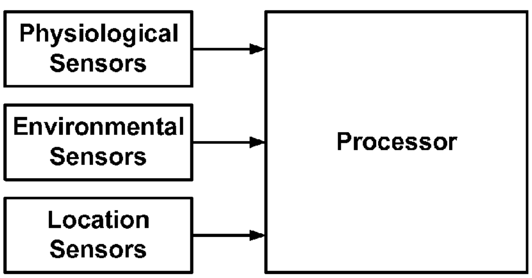


Figure 12C

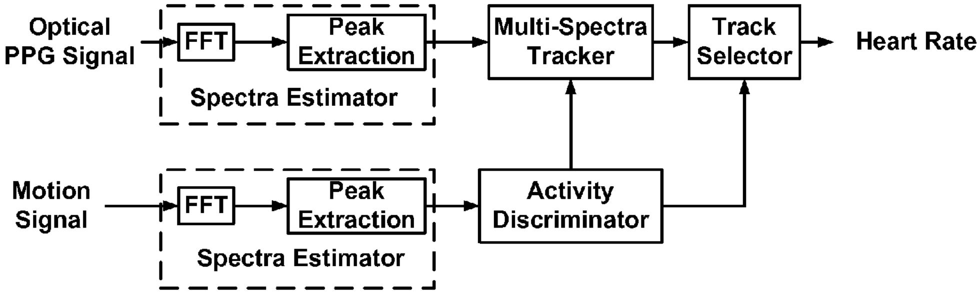


Figure 13A

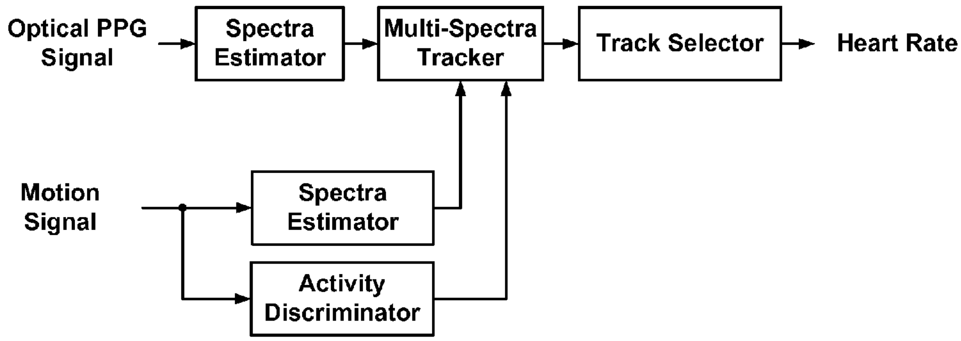


Figure 13B

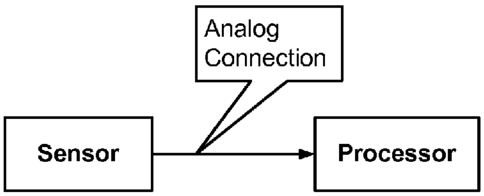


Figure 14A (Prior Art)

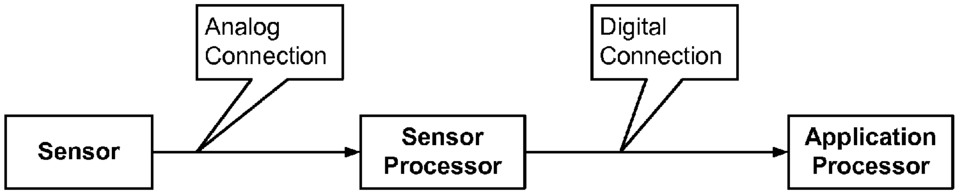


Figure 14B

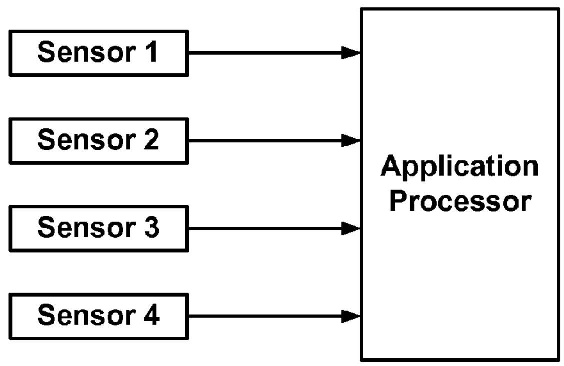


Figure 14C

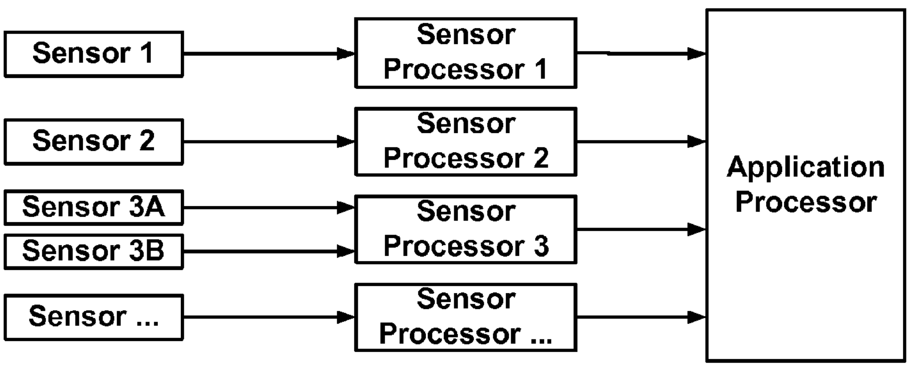


Figure 14D

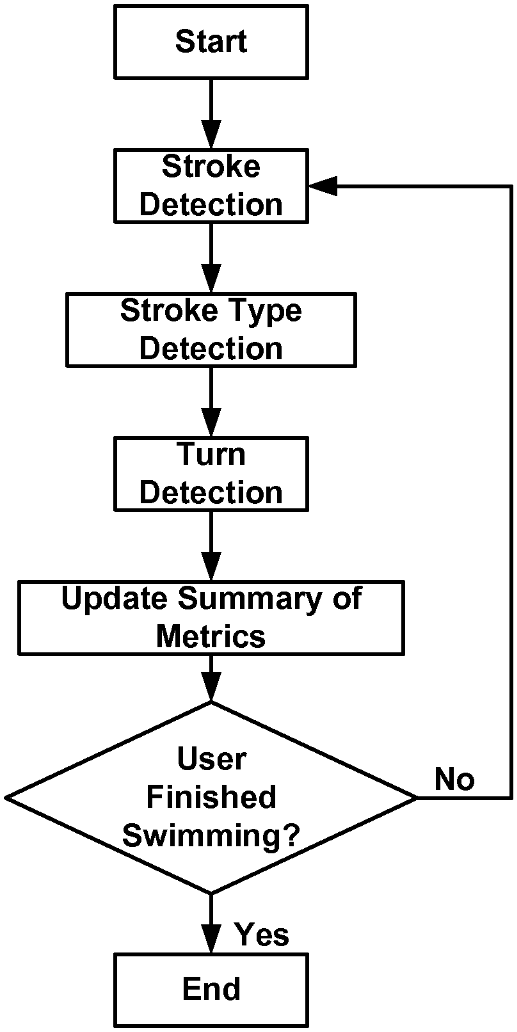

Start
Stroke Detection
Stroke Type Detection
Turn Detection
Update Summary of Metrics
User Finished Swimming?
No
Yes
End

Figure 15A

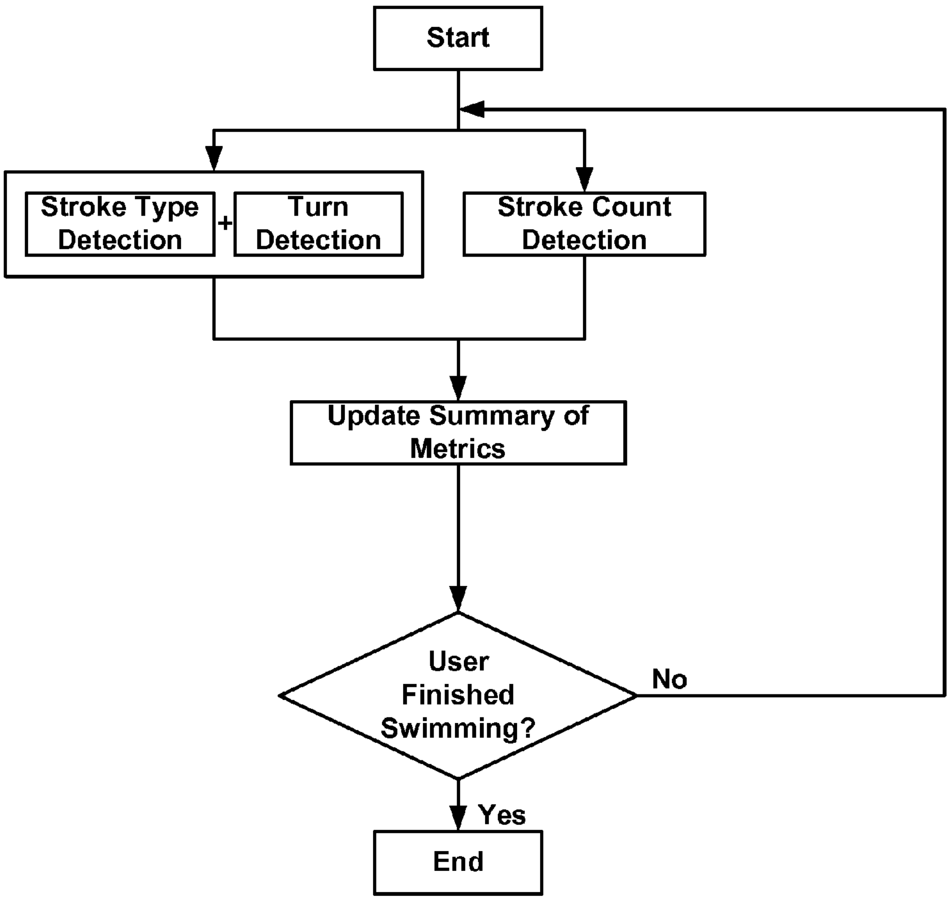

Start
Stroke Type Detection
+
Turn Detection
Stroke Count Detection
Update Summary of Metrics
User Finished Swimming?
No
Yes
End

Figure 15B

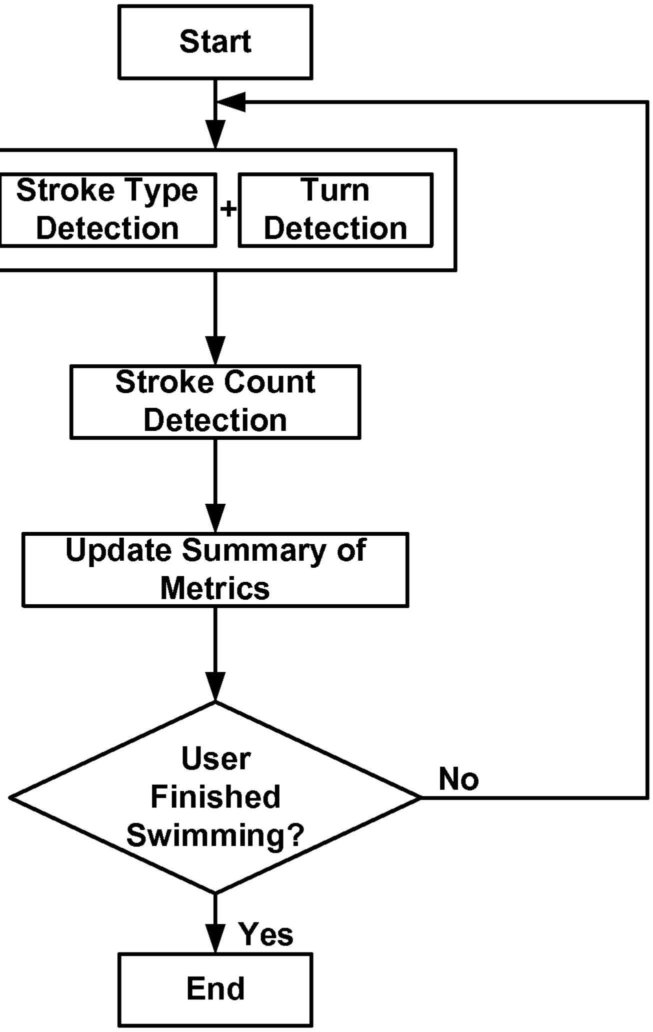

Start
Stroke Type Detection
+
Turn Detection
Stroke Count Detection
Update Summary of Metrics
User Finished Swimming?
No
Yes
End

Figure 15C

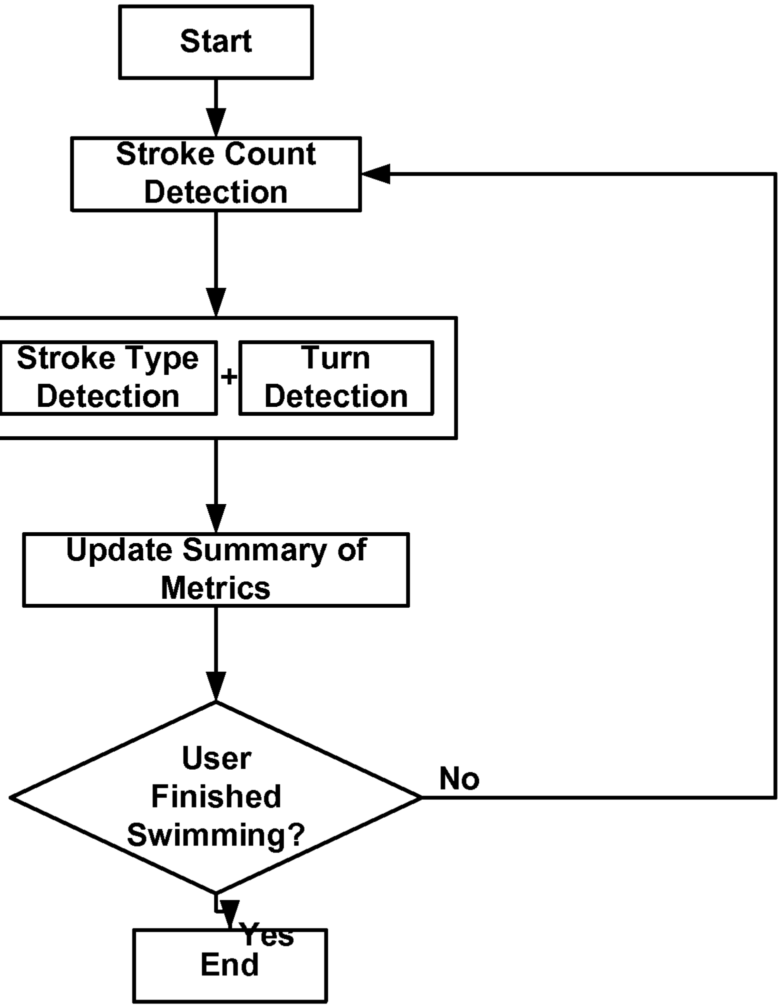

Start
Stroke Count Detection
Stroke Type Detection
+
Turn Detection
Update Summary of Metrics
User Finished Swimming?
No
Yes
End

Figure 15D

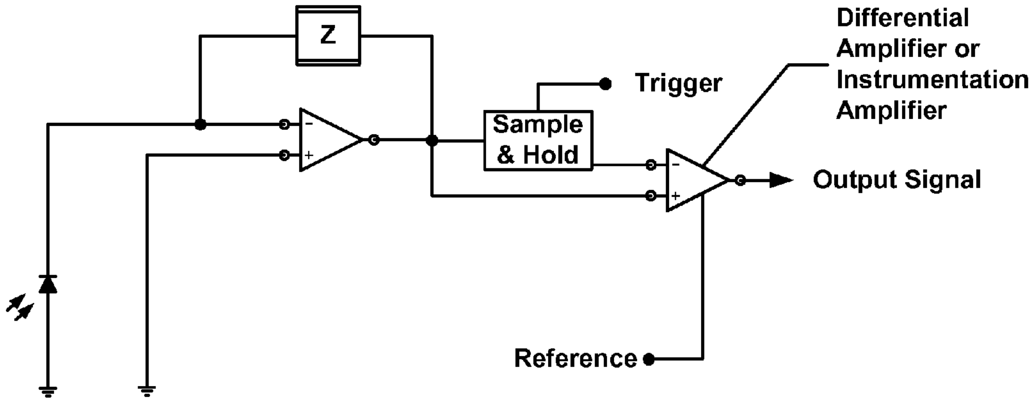


Figure 16A

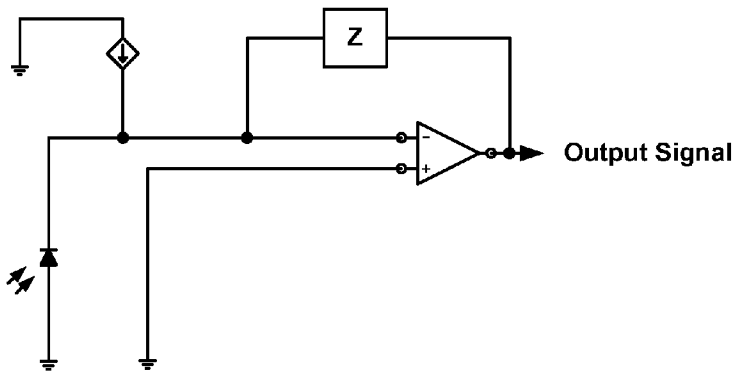


Figure 16B

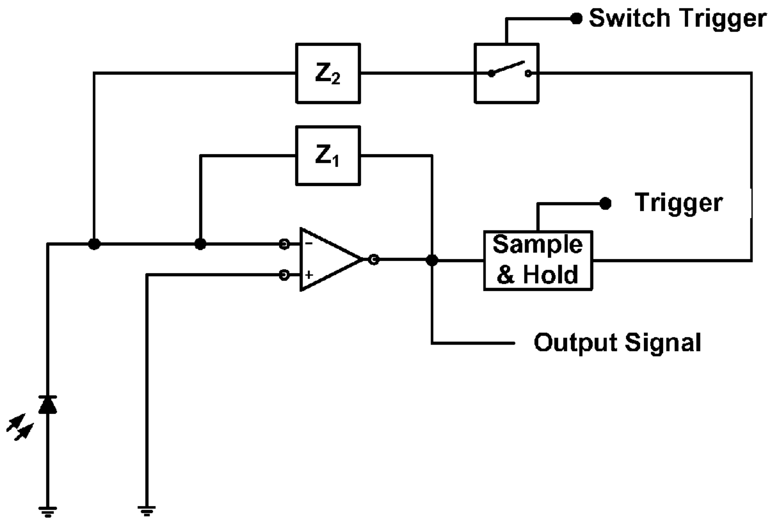


Figure 16C

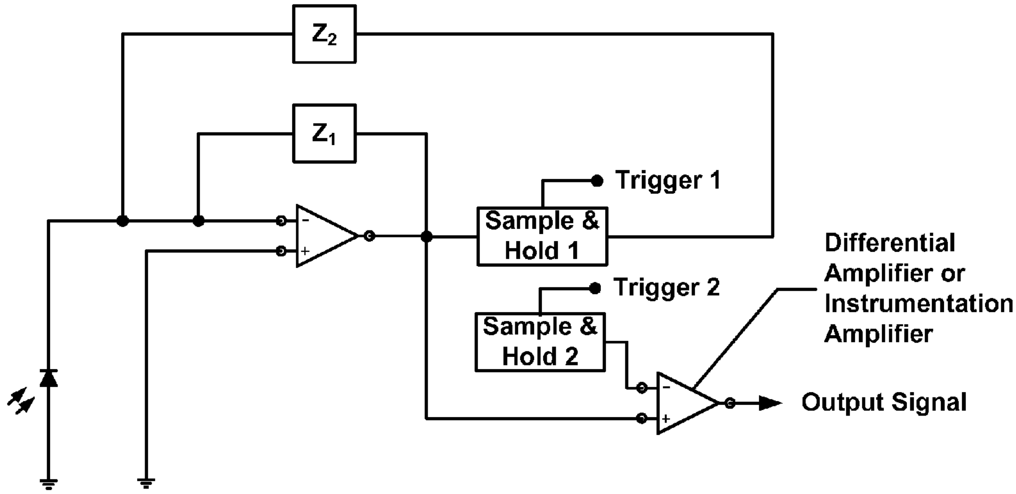


Figure 16D

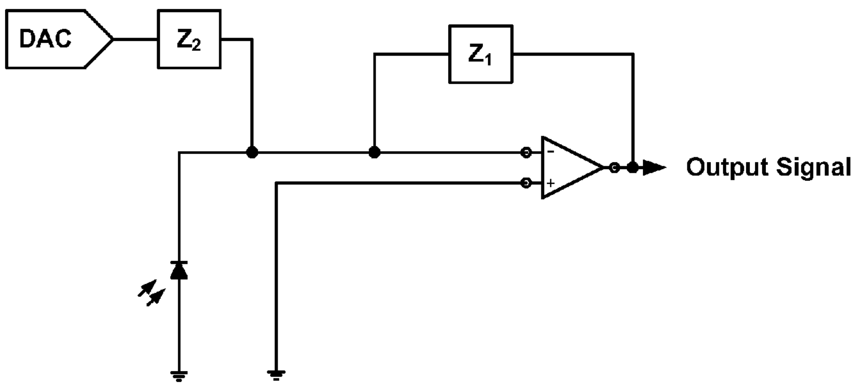


Figure 16E

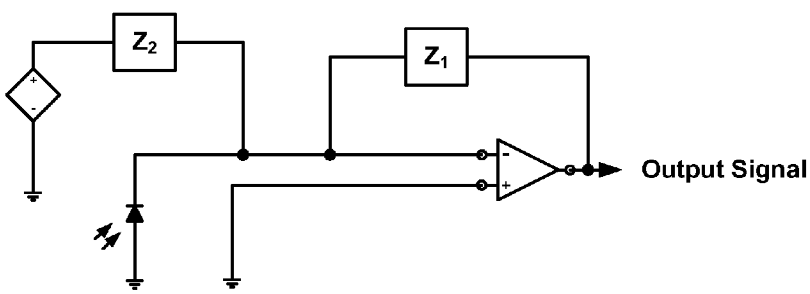


Figure 16F

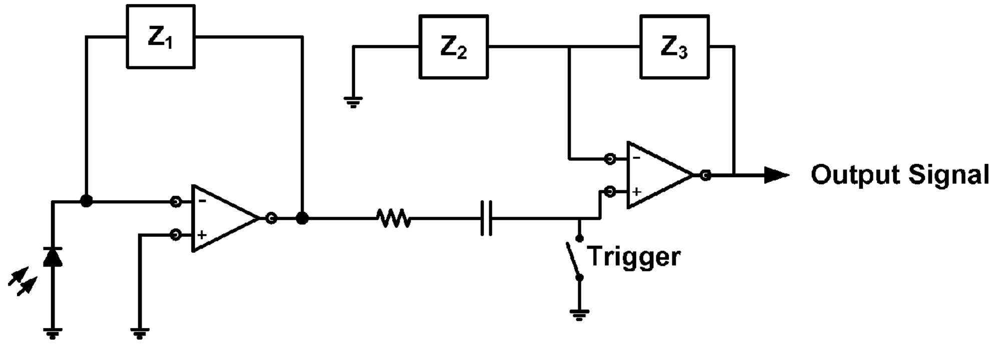


Figure 16G

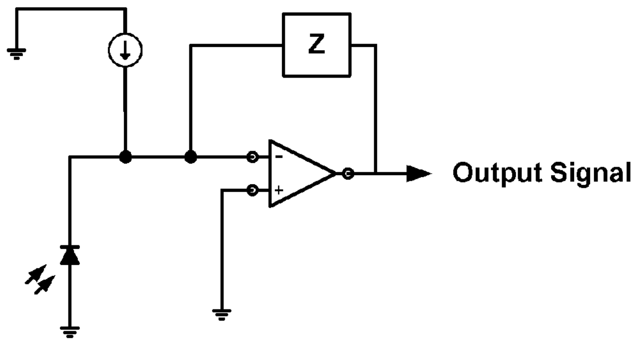


Figure 16H

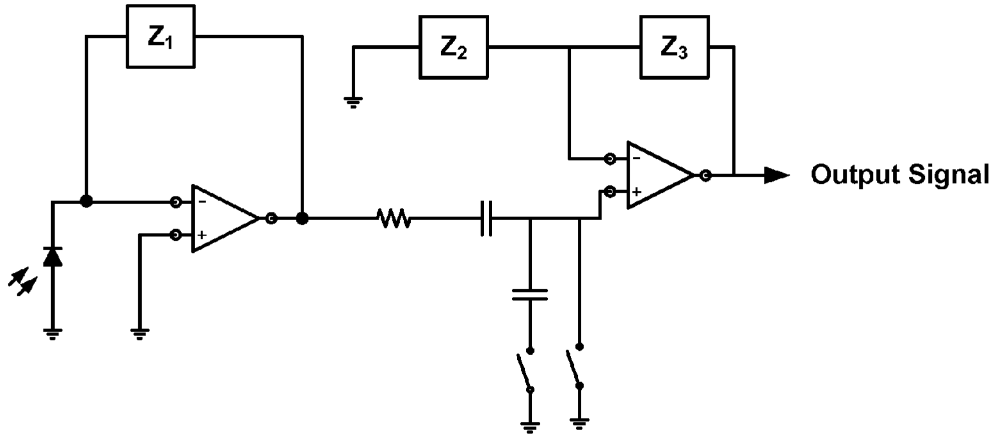


Figure 16I

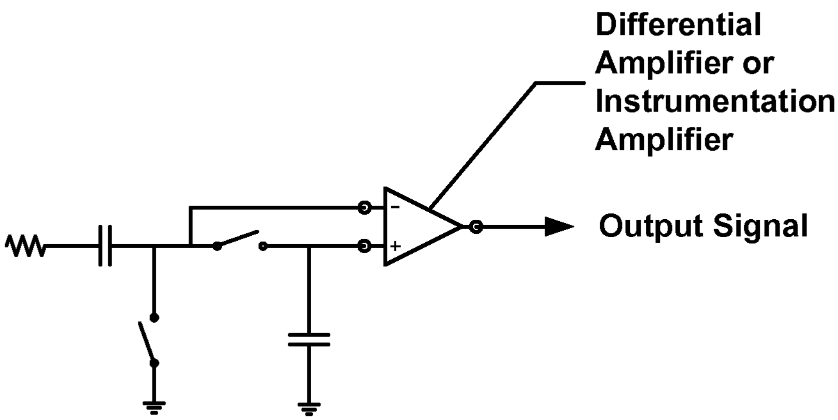
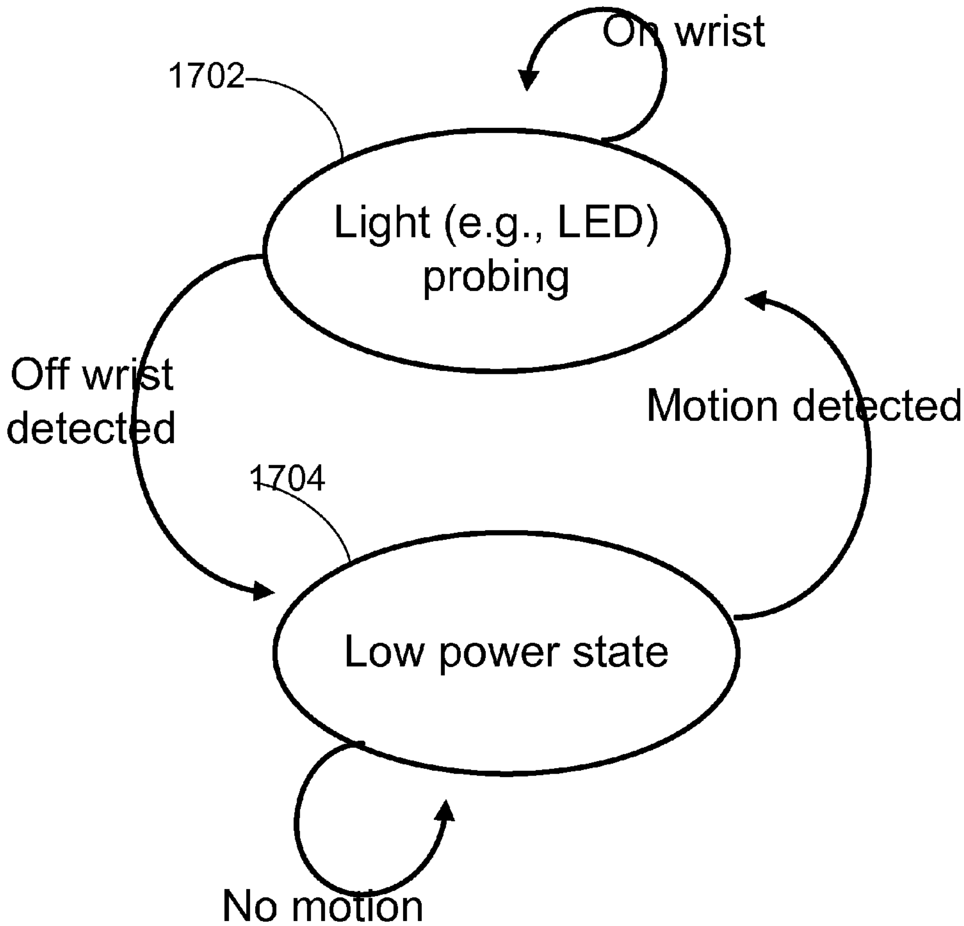

Differential
Amplifier or
Instrumentation
Amplifier
Output Signal

Figure 16J



On wrist
1702
Light (e.g., LED) probing
Off wrist detected
Motion detected
1704
Low power state
No motion

Figure 17A

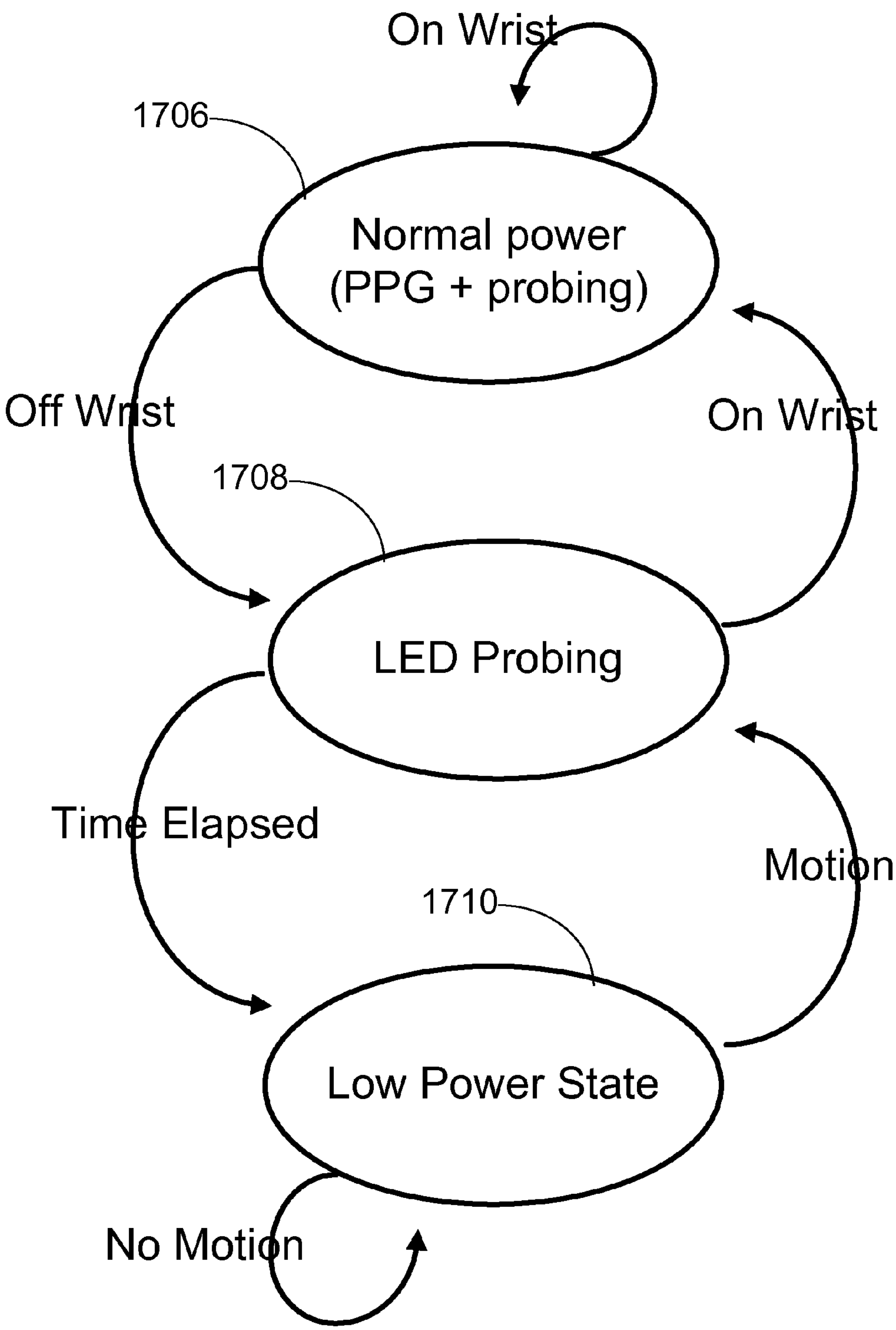

On Wrist
1706
Normal power (PPG + probing)
Off Wrist
On Wrist
1708
LED Probing
Time Elapsed
Motion
1710
Low Power State
No Motion

Figure 17B

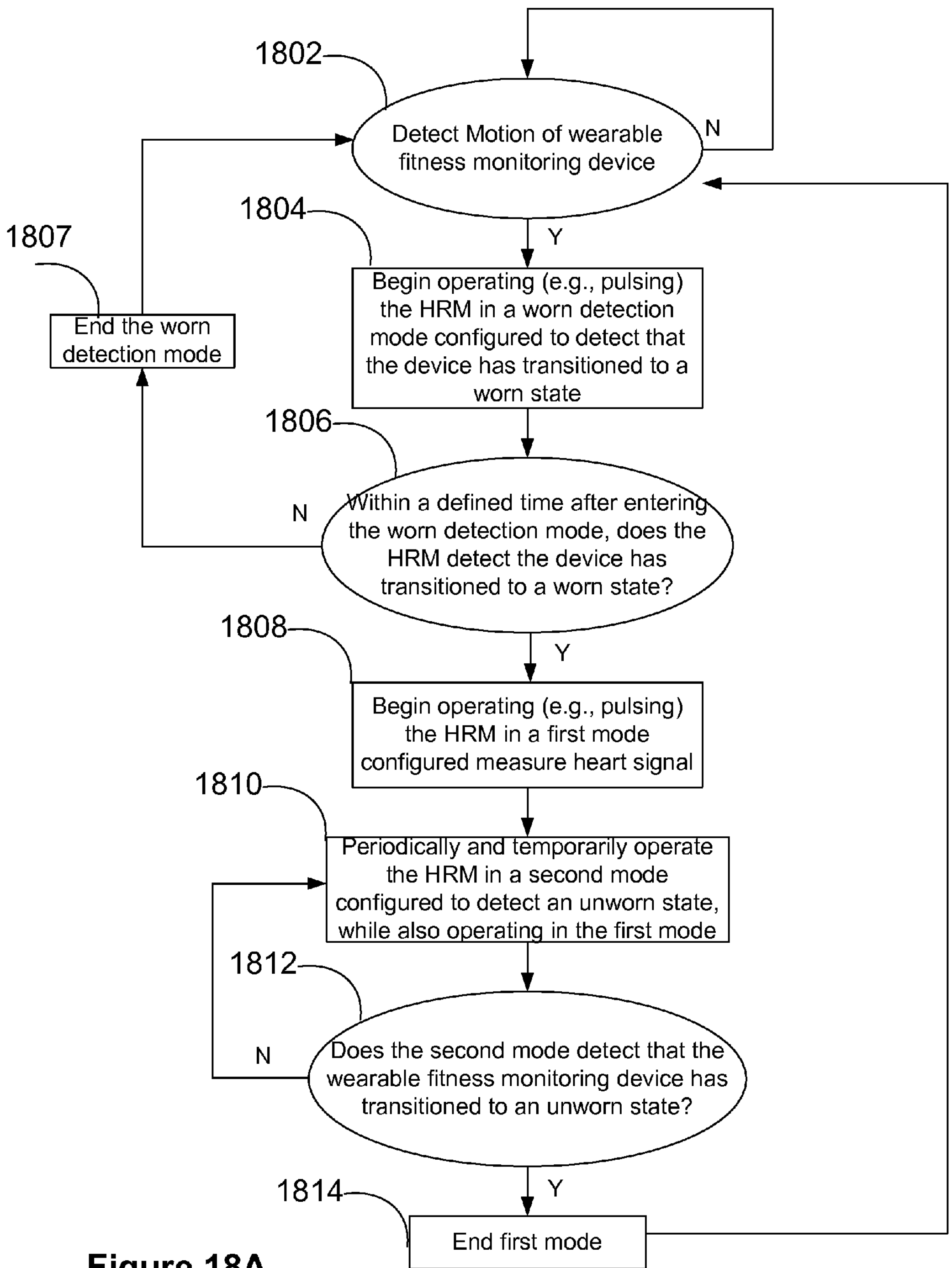
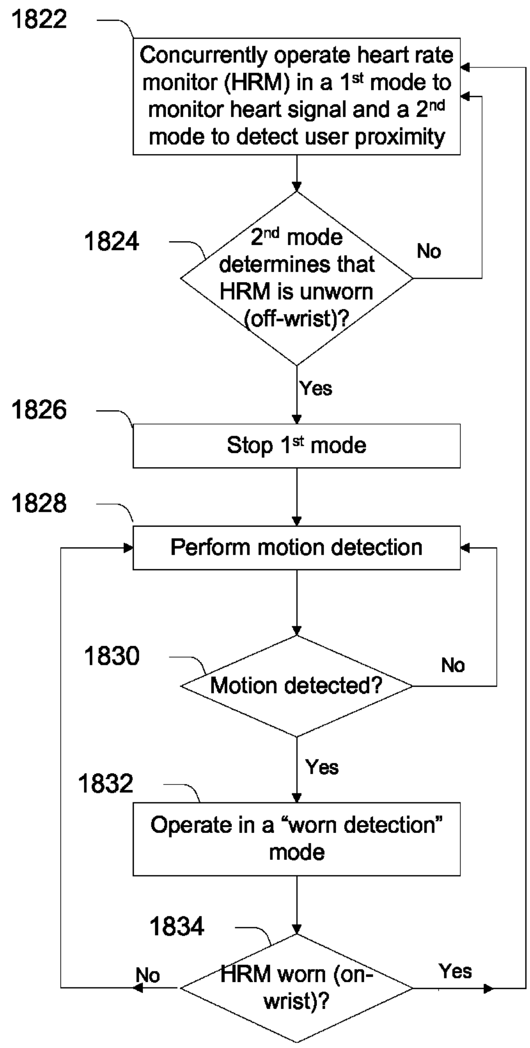

1802
Detect Motion of wearable fitness monitoring device
N
1804
Y
Begin operating (e.g., pulsing) the HRM in a worn detection mode configured to detect that the device has transitioned to a worn state
1807
End the worn detection mode
1806
N
Within a defined time after entering the worn detection mode, does the HRM detect the device has transitioned to a worn state?
1808
Y
Begin operating (e.g., pulsing) the HRM in a first mode configured measure heart signal
1810
Periodically and temporarily operate the HRM in a second mode configured to detect an unworn state, while also operating in the first mode
1812
N
Does the second mode detect that the wearable fitness monitoring device has transitioned to an unworn state?
1814
Y
End first mode

Figure 18A



1822
Concurrently operate heart rate monitor (HRM) in a 1st mode to monitor heart signal and a 2nd mode to detect user proximity
1824
2nd mode determines that HRM is unworn (off-wrist)?
No
Yes
1826
Stop 1st mode
1828
Perform motion detection
1830
Motion detected?
No
Yes
1832
Operate in a "worn detection" mode
1834
HRM worn (on-wrist)?
No
Yes

Figure 18B

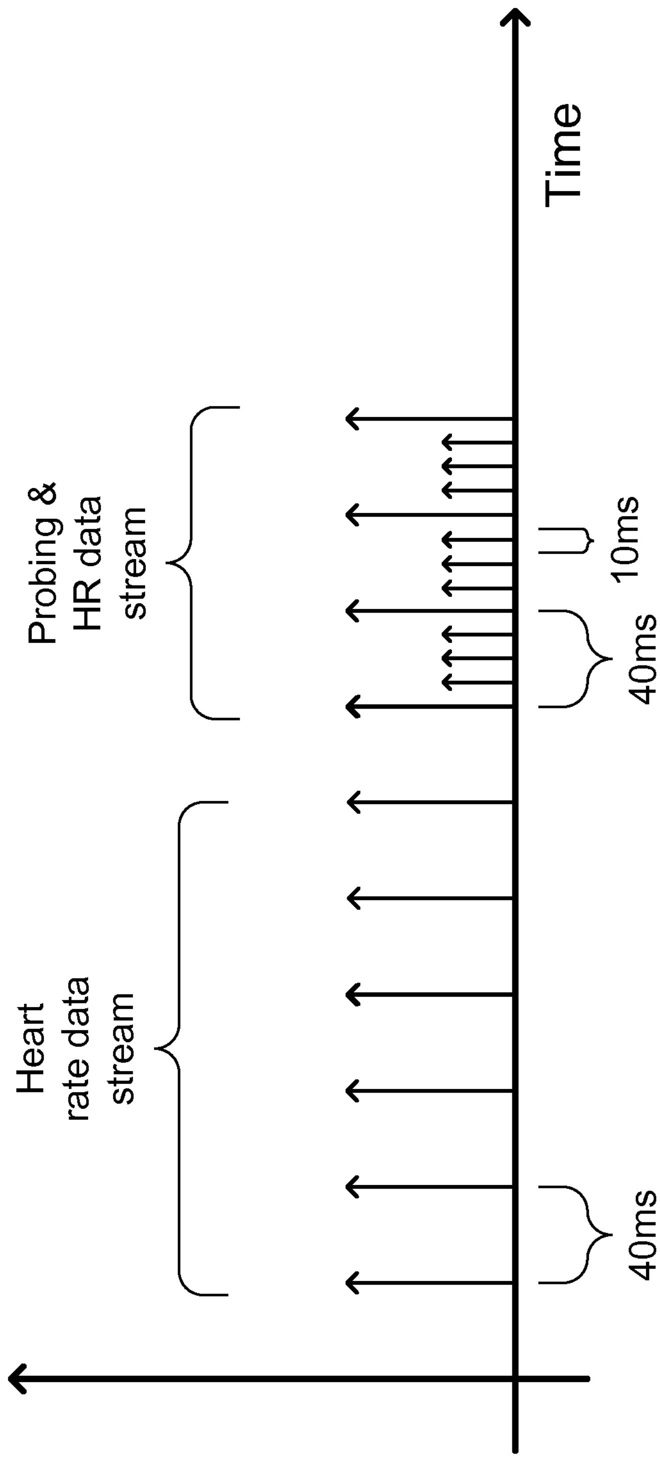

Time
Probing & HR data stream
10ms
40ms
Heart rate data stream
40ms

Figure 18C

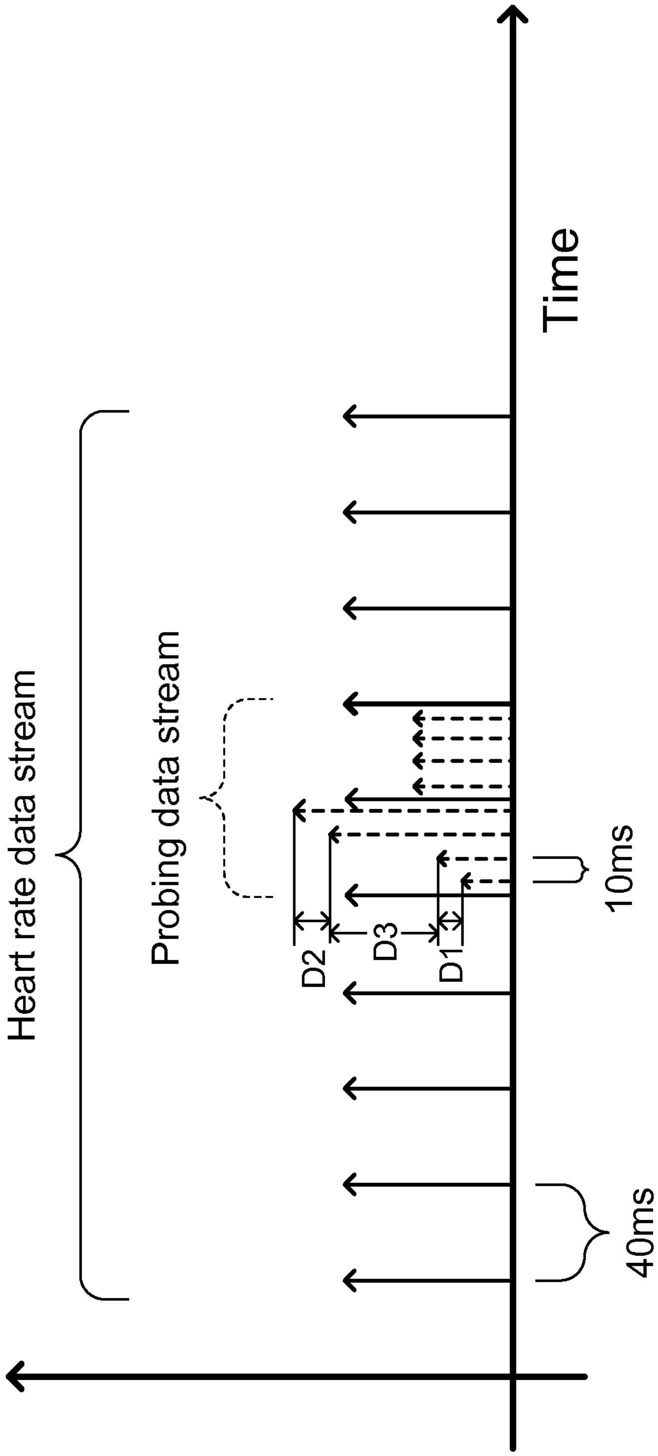

Time
Heart rate data stream
Probing data stream
D1
D2
D3
10ms
40ms

Figure 18D

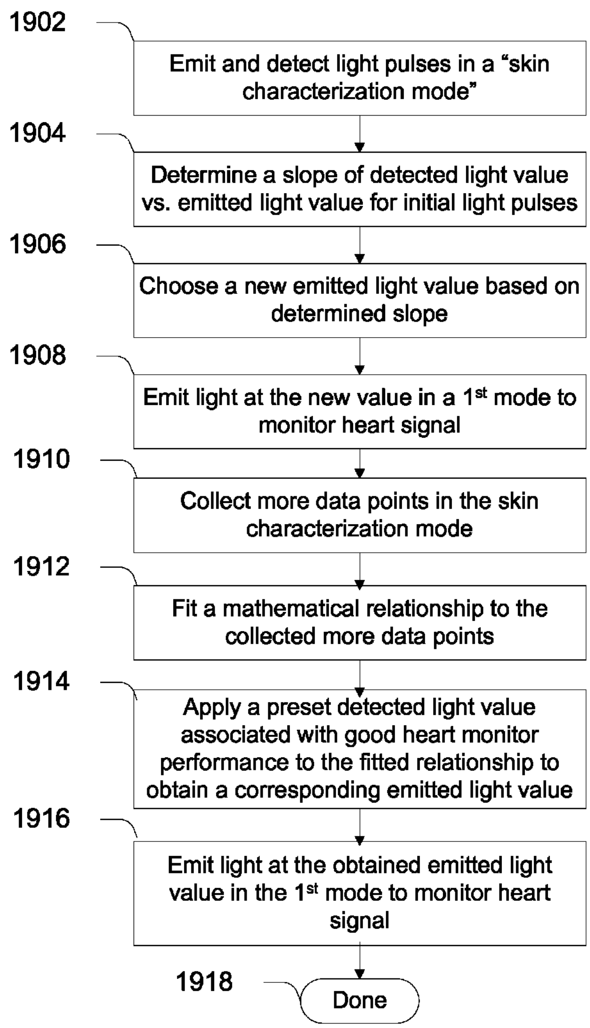

1902
Emit and detect light pulses in a "skin characterization mode"
1904
Determine a slope of detected light value vs. emitted light value for initial light pulses
1906
Choose a new emitted light value based on determined slope
1908
Emit light at the new value in a 1st mode to monitor heart signal
1910
Collect more data points in the skin characterization mode
1912
Fit a mathematical relationship to the collected more data points
1914
Apply a preset detected light value associated with good heart monitor performance to the fitted relationship to obtain a corresponding emitted light value
1916
Emit light at the obtained emitted light value in the 1st mode to monitor heart signal
1918
Done

Figure 19A

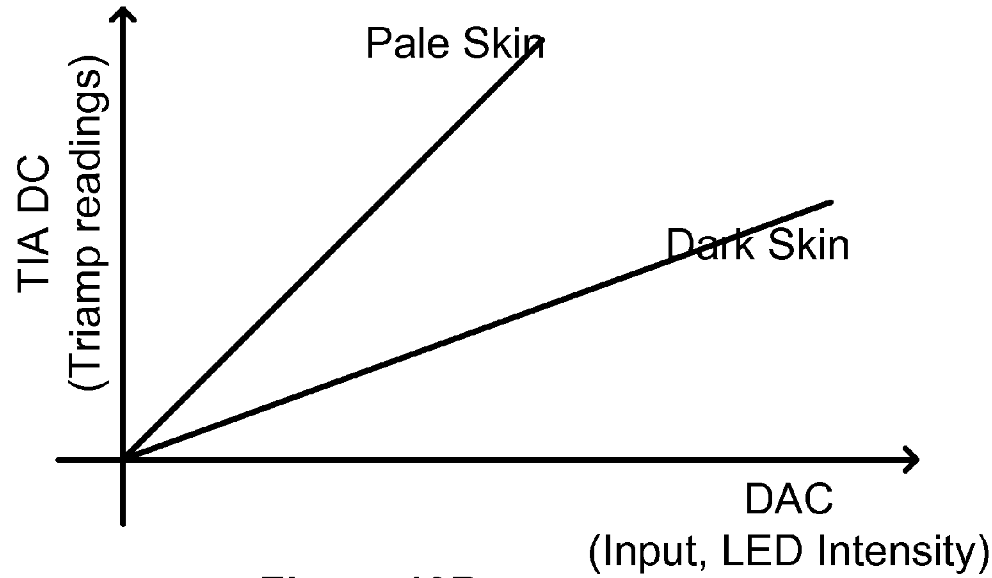


Figure 19B

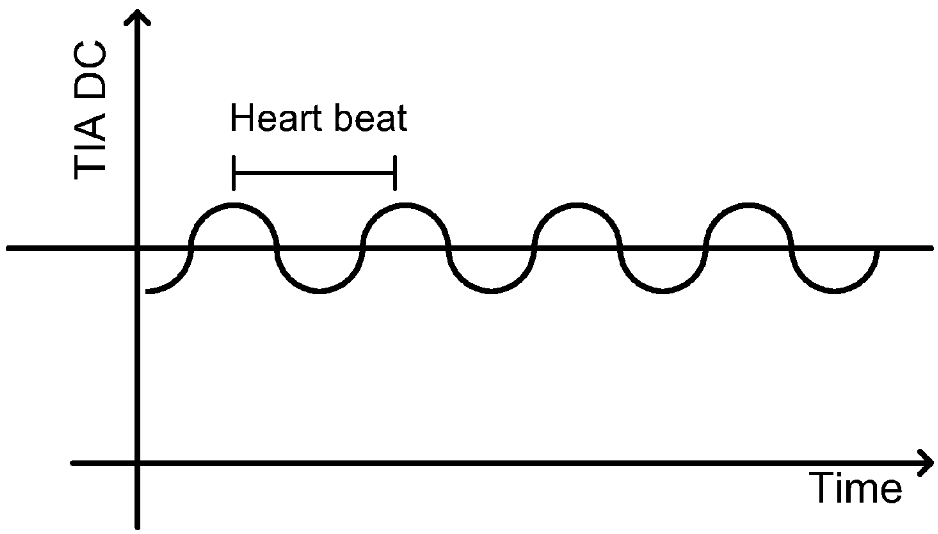


Figure 19C

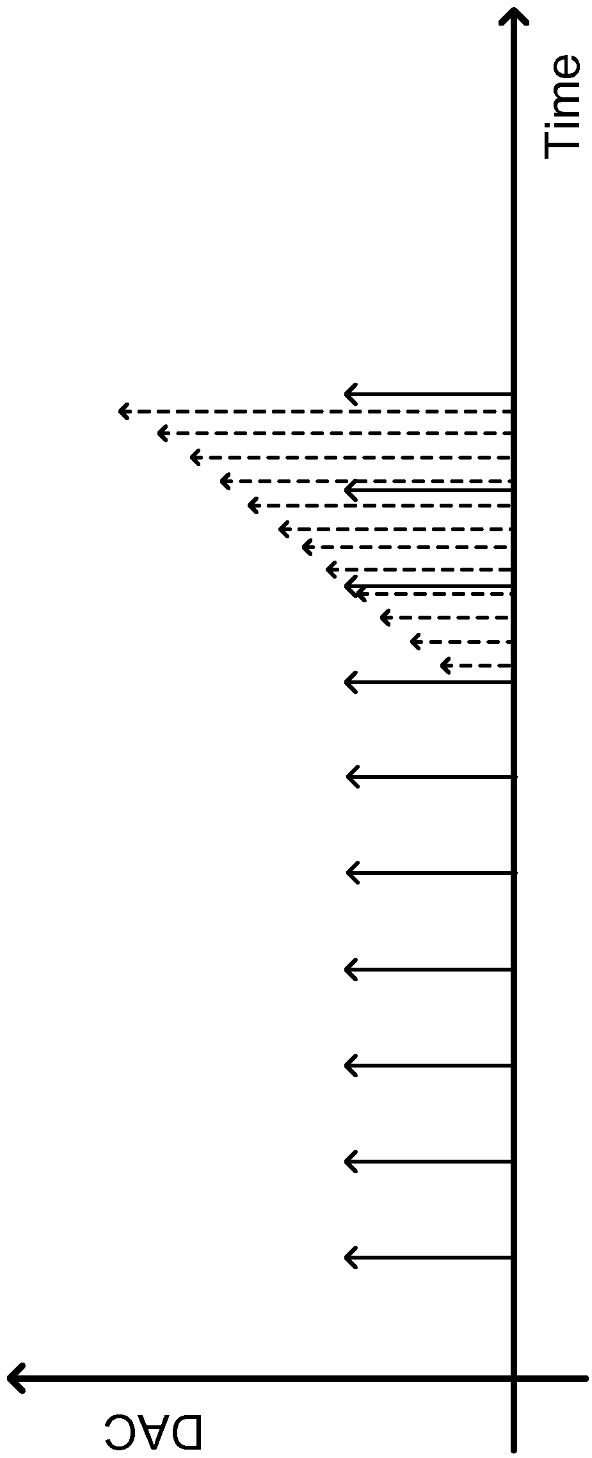


Figure 19D

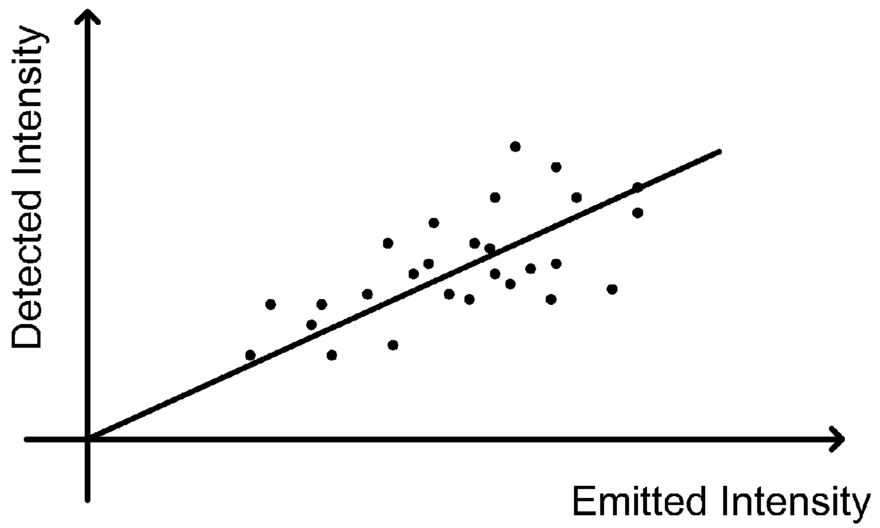


Figure 19E

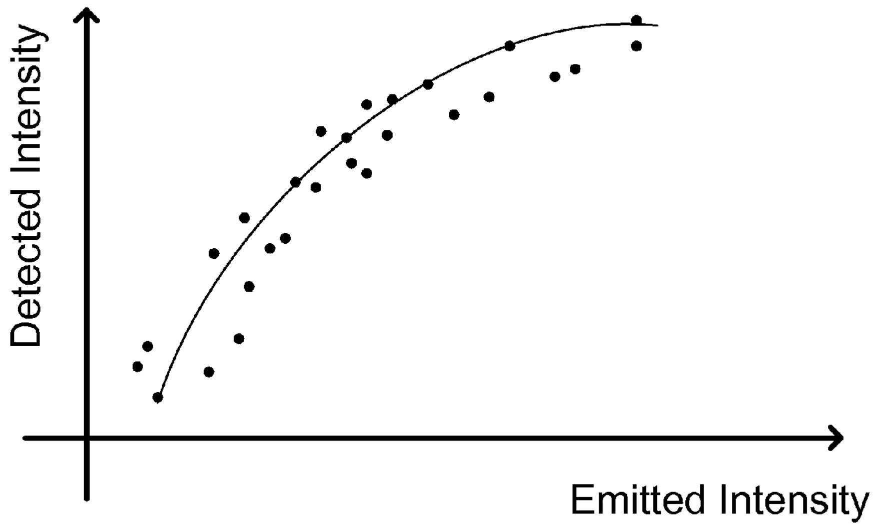


Figure 19F

WEARABLE HEART RATE MONITOR

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/292,669, titled "WEARABLE HEART RATE MONITOR" and filed on May 30, 2014, which is a continuation-in-part of U.S. patent application Ser. No. 13/924,784, titled "PORTABLE BIOMETRIC MONITORING DEVICES AND METHODS OF OPERATING SAME" and filed on Jun. 24, 2013, which claims benefit of priority under 35 U.S.C. §119(e) to U.S. Provisional Patent Application Nos. 61/662,961, titled "WIRELESS PERSONAL BIOMETRICS MONITOR" and filed on Jun. 22, 2012, 61/752,826, titled "PORTABLE MONITORING DEVICES AND METHODS OF OPERATING SAME" and filed on Jan. 15, 2013; moreover, this application claims benefit of priority under 35 U.S.C. §119(e) to U.S. Provisional Patent Application Nos. 61/830,600, titled "PORTABLE MONITORING DEVICES AND METHODS OF OPERATING SAME" and filed on Jun. 3, 2013, 61/946,439, titled "HEART RATE DATA COLLECTION" and filed on Feb. 28, 2014, 61/955,045, titled "GPS POWER CONSERVATION USING ENVIRONMENTAL DATA" and filed on Mar. 18, 2014, 61/973,614, titled "GPS ACCURACY REFINEMENT USING EXTERNAL SENSORS" and filed on Apr. 1, 2014, 62/001,624, titled "FITNESS MONITORING DEVICE WITH ALTIMETER" and filed on May 21, 2014, and 62/001,585, titled "WEARABLE HEART RATE MONITOR" and filed on May 21, 2014, all of which are hereby incorporated by reference herein in their entireties.

BACKGROUND

Recent consumer interest in personal health has led to a variety of personal health monitoring devices being offered on the market. Such devices, until recently, tended to be complicated to use and were typically designed for use with one activity, e.g., bicycle trip computers.

Recent advances in sensor, electronics, and power source miniaturization have allowed the size of personal health monitoring devices, also referred to herein as "biometric tracking" or "biometric monitoring" devices, to be offered in extremely small sizes that were previously impractical. For example, the Fitbit Ultra is a biometric monitoring device that is approximately 2" long, 0.75" wide, and 0.5" deep; it has a pixelated display, battery, sensors, wireless communications capability, power source, and interface button, as well as an integrated clip for attaching the device to a pocket or other portion of clothing, packaged within this small volume.

The disclosure provides methods and devices for activating, in energy efficient ways, HR monitor based on user motion and skin proximity. The disclosure also provides methods for operating the LED and photo detector of heart rate monitors to obtain accurate reading of heart rate tailored for different user characteristics such as skin colors.

SUMMARY

Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims. Note that the

relative dimensions of the following figures may not be drawn to scale unless specifically indicated as being scaled drawings.

Wearable fitness monitoring devices having heart rate monitoring functions and methods for operating the devices are provided in the disclosure.

Some embodiments of the disclosure provide a method of operating a heart rate monitor of a wearable fitness monitoring device having a plurality of sensors including the heart rate monitor. The method involves: (a) operating the heart rate monitor in a first mode while also operating in a second mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin, wherein the first mode is configured to determine one or more characteristics of a user's heartbeat waveform when the wearable fitness monitoring device is in near proximity to the user; (b) from information collected in the second mode, determining that the heart rate monitor is not proximate to the user's skin; and (c) in response to determining that the heart rate monitor is not proximate to the user's skin, ending operating the heart rate monitor in the first mode. In some embodiments, the heart rate monitor is an optical heart rate monitor. In some embodiments, the heart rate monitor includes a photoplethysmographic sensor. In some embodiments, the one or more characteristics of the user's heartbeat waveform include the user's heart rate.

In some embodiments, operation (a) above involves periodically operating the heart rate monitor in the second mode while continuously operating the heart rate monitor in the first mode. In some embodiments, operation (a) involves operating the heart rate monitor in the second mode occurs no more than about 50% of the time.

In some embodiments, operating the heart rate monitor in the second mode involves pulsing a light source in the heart rate monitor at a second mode frequency and detecting light from the light source at the second mode frequency; and operating the heart rate monitor in the first mode involves pulsing the light source in the heart rate monitor at a first mode frequency and detecting light from the light source at the first mode frequency. In some embodiments, the second mode frequency is greater than the first mode frequency.

In some embodiments, operating the heart rate monitor in the second mode involves pulsing a light source in the heart monitor at a second frequency; detecting light from the light source at the second frequency; and determining whether the light detected at the second frequency has an intensity and/or pattern indicating that the light from the light source has interacted with the user's skin. In some embodiments, the pulsing the light in the second mode source involves emitting a succession of light pulses, some having variable intensity and others having constant intensity.

In some embodiments, operating the heart rate monitor in the second mode involves: emitting a succession of light pulses of variable intensity; and determining whether detected light corresponding to the succession of light pulses has a variable response corresponding to the variable intensity of the light pulses.

In some embodiments, the disclosed method for operating the heart rate monitor further involves operating the heart rate monitor in a skin characterization mode configured to determine at least one setting for operating the heart rate monitor in the first mode. The operation in the skin characterization mode involves: (i) pulsing a light source in the heart monitor by emitting a succession of light pulses of variable intensity; (ii) detecting an intensity, a variation in intensity, and/or a pattern in intensity of light after the pulsed light has interacted with the user's skin; and (iii) determining a response charac-

teristic of the user's skin from the intensity, variation in intensity, and/or pattern of intensity detected in (ii). In some embodiments, the method further involves using the response characteristic of the user's skin to adjust the heart rate monitor's gain and/or light emission intensity for operating in the first mode. In some embodiments, the response characteristic is dependent on the opacity of the user's skin. In some embodiments, the emitted succession of light pulses of variable intensity from (i) is used in the second mode as well as the skin characterization mode. In some embodiments, operating the heart rate monitor in the skin characterization mode involves periodically operating the heart rate monitor in the skin characterization mode while continuously operating the heart rate monitor in the first mode.

In some embodiments, the plurality of sensors of the device includes a motion detecting sensor. In some embodiments, the motion detecting sensor includes an accelerometer, a magnetometer, an altimeter, a GPS detector, or a combination of any of these. In some embodiments, the disclosed method for operating the heart rate monitor involves determining from information output by the motion detecting sensor that the wearable fitness monitoring device has had been still for at least a defined period; and in response to detecting that the wearable fitness monitoring device has had been still for at least the defined period, performing operation (c) described above.

In some embodiments, the method for operating the heart rate monitor further involves, prior to (a) while the first mode is not operating: (i) detecting motion of the wearable fitness monitoring device using a motion detecting sensor and/or detecting proximity of the heart rate monitor to the user' skin by operating the heart rate monitor in a third mode; and (ii) initiating operation of the first mode of the heart rate monitor when the wearable fitness monitoring device is determined to be in near proximity to the user.

The embodiments described above relate to detecting the device in an unworn state, while the ensuing embodiments relate to detecting the device in a worn state.

Some embodiments provide a method of operating a heart rate monitor of a wearable fitness monitoring device having a plurality of sensors including the heart rate monitor and a motion detecting sensor. The method involves: (a) detecting motion of the wearable fitness monitoring device using the motion detecting sensor; (b) in response to detecting the motion in (a), operating the heart rate monitor in a worn detection mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin; and (c) upon determining via the worn detection mode that the wearable fitness monitoring device is proximate to the user's skin, operating the heart rate monitor in a first mode configured to determine one or more characteristics of the user's heartbeat waveform. In some embodiments, the worn detection mode occurs no more than about 50% of the time. In some embodiments, (a) is performed when the heart rate monitor is not operating or is operating in a low power mode. In some embodiments, operation (a) involves detecting an output from the motion detecting sensor, wherein the output exceeds a defined threshold.

In some embodiments, the method further including prior to (a): (i) operating the heart rate monitor in the first mode while also operating in a second mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin; (ii) from information collected in the second mode, determining that the heart rate monitor is not proximate to the user's skin; and (iii) in response to determining that the heart rate monitor is not proximate to the user's skin, ending operating the heart rate monitor in the first mode.

In some embodiments, operating the heart rate monitor in the worn detection mode involves pulsing a light source in the heart rate monitor at a worn detection mode frequency and detecting light from the light source at the worn detection mode frequency. In some embodiments, operating the heart rate monitor in the first mode involves pulsing the light source in the heart rate monitor at a first mode frequency and detecting light from the light source at the first mode frequency. In some embodiments, the worn detection mode frequency is greater than the first mode frequency.

In some embodiments, operating the heart rate monitor in the worn detection mode involves: emitting light pulses from a light source in the heart rate monitor having a second frequency and/or phase; detecting light from the light source at the second frequency and/or phase; and determining whether the light detected at the second frequency and/or phase has an intensity and/or pattern indicating that the light from the light source has interacted with the user's skin. In some embodiments, emitting light pulses from the light source involves emitting a succession of light pulses having variable intensity. In some embodiments, a first one of the succession of light pulses has an intensity at least 5 times greater than a second one of the succession of light pulses. In some embodiments, the succession of light pulses includes a first set of pulses having an intensity providing variable response when interacting with light skin, and the succession of light pulses also includes a second set of pulses having an intensity providing a variable response when interacting with dark skin. In some embodiments, operating the heart rate monitor in the worn detection mode involves: emitting a succession of light pulses of variable intensity; and determining whether detected light corresponding to the succession of light pulses has a variable response corresponding to the variable intensity of the light pulses.

In some embodiments, the method of operating a heart rate monitor of a wearable fitness monitoring device further involves: determining from information output by the motion detecting sensor that the wearable fitness monitoring device has been still for at least a defined period; and in response to detecting that the wearable fitness monitoring device has been still for at least the defined period, powering down the device.

Some embodiments of the disclosure provide methods for determining skin characteristics of the user wearing a fitness monitoring device. Some embodiments provide methods for adjusting the operation of a heart rate monitor of the fitness monitoring device. Some embodiments provide a method of operating a heart rate monitor of a wearable fitness monitoring device to adjust at least one setting for operating the heart rate monitor. Operation of the heart rate monitor involves: (a) pulsing a light source in the heart monitor in a skin characterization mode by emitting a succession of light pulses, at least some having variable intensity with respect to one another; (b) detecting a variation in intensity of light from the light pulses emitted in the skin characterization mode after the light has interacted with the user's skin; (c) determining a response characteristic of the user's skin from the variation in intensity of light detected in (b); and (d) using the response characteristic of the user's skin to adjust a gain and/or light emission intensity of the heart rate monitor operating in a first mode for detecting one or more characteristics of the user's heartbeat waveform.

In some embodiments of the method, the response characteristic is dependent on an opacity of the user's skin. In some embodiments, operating in the first mode and operating in the skin characterization mode are performed concurrently. In some embodiments, operating in the first mode and operating in the skin characterization mode concurrently involves peri-

odically determining a response characteristic of the user's skin while continuously operating in the first mode. In some embodiments, the skin characterization mode occurs no more than about 50% of the time.

In some embodiments, operating in the first mode involves pulsing the light source in the heart rate monitor at a first frequency and detecting light from the light source, after the light has interacted with the user's skin, at the first frequency. In some embodiments, operating in the skin characterization mode involves pulsing the light source in the heart rate monitor at a second frequency and detecting light from the light source at the second frequency. In some embodiments, the second frequency is greater than the first frequency.

In some embodiments, the operation of determining the response characteristic of the user's skin involves determining an intensity level and/or pattern of two or more light pulses detected at the second frequency. In some embodiments, the succession of light pulses includes some light pulses having variable intensity and others having constant intensity.

In some embodiments, the succession of light pulses includes at least two light pulses of variable intensity. In some embodiments, the succession of light pulses includes at least four light pulses of variable intensity. In some embodiments, the succession of light pulses emitted in the skin characterization mode include at least two light pulses of variable intensity. The operation of determining a response characteristic of the user's skin in (c) involves determining a function or characteristic of the intensity variation of light from the light pulses detected in (b). The function or characteristic of the intensity variation is the response characteristic of the user's skin used to adjust the gain and/or light emission intensity of the heart rate monitor operating in a first mode.

In some embodiments, determining the function or characteristic involves determining a slope of the intensity variation of light from the light pulses detected in (b).

In some embodiments, adjusting the heart rate monitor's gain and/or light emission intensity for operating in the first mode involves reducing the emission intensity.

In some embodiments, the wearable fitness monitoring device includes a motion detecting sensor. In some embodiments, the motion detecting sensor includes an accelerometer, a magnetometer, an altimeter, a GPS detector, a gyroscope, or a combination of any of these.

Some embodiments provide a method of operating a heart rate monitor of a wearable fitness monitoring device, the heart rate monitor having a light source and a light detector. The method involves adjusting the heart rate monitor's operation(s) based on a user's skin characteristics to improve performance. The method involves: (a) operating the heart rate monitor in a first mode while also operating in a skin characterization mode for determining a characteristic of a user's skin. The first mode is configured to determine one or more characteristics of the user's heartbeat waveform. The skin characterization mode operation involves generating data points representing emission intensity from the light source and corresponding detection levels from the light detector. The method further involves: (b) fitting the data points of the skin characterization mode to a mathematical relationship relating light source emission intensity to light detector detection level; (c) using the mathematical relationship to determine a light source emission intensity setting that provides a predetermined light detector detection level identified as providing good heart rate monitor performance; and (d) adjusting the light source emission intensity to said setting determined in (c) for operating in the first mode.

In some embodiments, the mathematical relationship is linear. In some embodiments, the pre-determined light detector detection level was previously determined to have a high signal to noise ratio. In some embodiments, the method further involves, prior to (b), determining a slope of a line fitting the data points representing emission intensity from the light source and corresponding detection levels from the light detector; and setting the light source emission intensity for operating in the first mode based on the determined slope and pre-set values of emission intensity levels.

In some embodiments, the first mode and the skin characterization mode are performed concurrently. In some embodiments, operating in the first mode and operating in the skin characterization mode concurrently involves periodically determining a response characteristic of the user's skin while continuously operating in the first mode. In some embodiments, the skin characterization mode occurs no more than about 50% of the time.

In some embodiments, operating in the first mode involves pulsing the light source in the heart rate monitor at a first frequency and detecting light from the light source, after the light has interacted with the user's skin, at the first frequency. In some embodiments, operating in the skin characterization mode involves pulsing a light source in the heart rate monitor at a second frequency and detecting light from the light source, after the light has interacted with the user's skin, at the second frequency. In some embodiments, the second frequency is greater than the first frequency.

In some embodiments, operating in the skin characterization mode further involves determining an intensity level and/or pattern of two or more light pulses, after the light has interacted with the user's skin, detected at the second frequency.

In some embodiments, operating the heart rate monitor in the skin characterization mode involves emitting a succession of light pulses, and wherein some of the light pulses have variable intensity and other light pulses having constant intensity compared to one another.

In some embodiments, operating the heart rate monitor in the skin characterization mode involves emitting a succession of light pulses. In some embodiments, at least two of the light pulses have variable intensity compared to one another. In some embodiments, at least four of the light pulses have variable intensity compared to one another.

Some embodiments of the disclosure provide a wearable fitness monitoring device having a motion sensor configured to provide output corresponding to motion by a user wearing the fitness monitoring device and a photoplethysmographic (PPG) sensor. The PPG sensor includes (i) a periodic light source, (ii) a photo detector positioned to receive periodic light emitted by the periodic light source after interacting with a user's skin, and (iii) circuitry determining a user's heart rate from an output of the photo detector. In some embodiments, the periodic light source includes two periodic light sources straddling the photo detector. In some embodiments, the photoplethysmographic sensor further includes a housing having a recess in which the photo detector is disposed. In some embodiments, the housing of the photoplethysmographic sensor further includes a second recess in which the periodic light source is disposed. In some embodiments, the housing of the photoplethysmographic sensor protrudes at least about 1 mm above a base surface of the wearable fitness monitoring device and is configured to press against the user's skin when worn.

In some embodiments, the photoplethysmographic sensor further includes a spring configured to resist compression when the protruding housing presses against the user's skin.

In some embodiments, the photoplethysmographic sensor further includes an IML film over the photo detector and the periodic light source. In some embodiments, wherein the periodic light source of the PPG sensor is an LED.

In many embodiments, wearable fitness monitoring devices are configured to perform features and operations associated with various methods described elsewhere herein.

Some embodiments of the disclosure provide a wearable fitness monitoring device having a motion sensor, a PPG sensor, and a control logic. The PPG sensor includes (i) a periodic light source, (ii) a photo detector positioned to receive periodic light emitted by the periodic light source after interacting with a user's skin, and (iii) circuitry determining a user's heart rate from an output of the photo detector. The control logic is configured to: (a) operate the heart rate monitor in a first mode while also operating in a second mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin, where the first mode is configured to determine one or more characteristics of a user's heartbeat waveform when the wearable fitness monitoring device is in near proximity to the user; (b) from information collected in the second mode, determine that the heart rate monitor is not proximate to the user's skin; and (c) in response to determining that the heart rate monitor is not proximate to the user's skin, end operating the heart rate monitor in the first mode. In some embodiments, operating the heart rate monitor in the second mode involves pulsing a light source in the heart rate monitor at a second mode frequency and detecting light from the light source at the second mode frequency. In some embodiments, operating the heart rate monitor in the first mode involves pulsing the light source in the heart rate monitor at a first mode frequency and detecting light from the light source at the first mode frequency.

In some embodiments, the control logic of the wearable fitness monitoring device is configured to: (a) detect motion of the wearable fitness monitoring device using the motion detecting sensor; (b) in response to detecting the motion in (a), operate the heart rate monitor in a worn detection mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin; and (c) upon determining via the worn detection mode that the wearable fitness monitoring device is proximate to the user's skin, operate the heart rate monitor in a first mode configured to determine one or more characteristics of the user's heartbeat waveform.

In other embodiments, the control logic of the wearable fitness monitoring device is configured to: (a) pulse a light source in the heart monitor in a skin characterization mode by emitting a succession of light pulses, at least some having variable intensity with respect to one another; (b) detect a variation in intensity of light from the light pulses emitted in the skin characterization mode after the light has interacted with the user's skin; (c) determine a response characteristic of the user's skin from the variation in intensity of light detected in (b); and (d) use the response characteristic of the user's skin to adjust a gain and/or light emission intensity of the heart rate monitor operating in a first mode for detecting one or more characteristics of the user's heartbeat waveform.

In further embodiments, the control logic of the wearable fitness monitoring device is configured to: (a) operate the heart rate monitor in a first mode while also operating in a skin characterization mode for determining a characteristic of a user's skin. The first mode is configured to determine one or more characteristics of the user's heartbeat waveform, and the skin characterization mode involves generating data points representing emission intensity from the light source and corresponding detection levels from the light detector. The control logic is further configured to: (b) fit the data points of the skin characterization mode to a mathematical relationship relating light source emission intensity to light detector detection level; (c) use the mathematical relationship to determine a light source emission intensity setting that provides a predetermined light detector detection level identified as providing good heart rate monitor performance; and (d) adjust the light source emission intensity to said setting determined in (c) for operating in the first mode.

BRIEF DESCRIPTION OF DRAWINGS

The various implementations disclosed herein are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings, in which like reference numerals may refer to similar elements.

FIG. **1** illustrates an example portable monitoring device which enables user interaction via a user interface.

FIG. **2**A illustrates an example portable monitoring device which may be secured to the user through the use of a band.

FIG. **2**B provides a view of the example portable monitoring device of FIG. **2**A which shows the skin-facing portion of the device.

FIG. **2**C provides a cross-sectional view of the portable monitoring device of FIG. **2**A.

FIG. **3**A provides a cross sectional view of a sensor protrusion of an example portable monitoring device.

FIG. **3**B depicts a cross sectional view of a sensor protrusion of an example portable monitoring device; this protrusion is similar to that presented in FIG. **3**A with the exception that the light sources and photodetector are placed on a flat and/or rigid PCB.

FIG. **3**C provides another cross-sectional view of an example PPG sensor implementation.

FIG. **4**A illustrates an example of one potential PPG light source and photodetector geometry.

FIGS. **4**B and **4**C illustrate examples of a PPG sensor having a photodetector and two LED light sources.

FIG. **5** Illustrates an example of an optimized PPG detector that has a protrusion with curved sides so as not to discomfort the user.

FIG. **6**A illustrates an example of a portable monitoring device having a band; optical sensors and light emitters may be placed on the band.

FIG. **6**B illustrates an example of a portable biometric monitoring device having a display and wristband. Additionally, optical PPG (e.g., heart rate) detection sensors and/or emitters may be located on the side of the biometric monitoring device. In one embodiment, these may be located in side-mounted buttons.

FIG. **7** depicts a user pressing the side of a portable biometric monitoring device to take a heart rate measurement from a side-mounted optical heart rate detection sensor. The display of the biometric monitoring device may show whether or not the heart rate has been detected and/or display the user's heart rate.

FIG. **8** illustrates functionality of an example biometric monitoring device smart alarm feature.

FIG. **9** illustrates an example of a portable biometric monitoring device that changes how it detects a user's heart rate based on how much movement the biometric monitoring device is experiencing.

FIG. **10** illustrates an example of a portable biometric monitoring device that has a bicycle application on it that may display bicycle speed and/or pedaling cadence, among other metrics.

FIG. **11**A illustrates an example block diagram of a PPG sensor which has a light source, light detector, ADC, processor, DAC/GPIOs, and light source intensity and on/off control.

FIG. **11**B illustrates an example block diagram of a PPG sensor that is similar to that of FIG. **11**A which additionally uses a sample-and-hold circuit as well as analog signal conditioning.

FIG. **11**C illustrates an example block diagram of a PPG sensor that is similar to that of FIG. **11**A which additionally uses a sample-and-hold circuit.

FIG. **11**D illustrates an example block diagram of a PPG sensor having multiple switchable light sources and detectors, light source intensity/on and off control, and signal conditioning circuitry.

FIG. **11**E illustrates an example block diagram of a PPG sensor which uses synchronous detection. To perform this type of PPG detection, it has a demodulator.

FIG. **11**F illustrates an example block diagram of a PPG sensor which, in addition to the features of the sensor illustrated in FIG. **11**A, has a differential amplifier.

FIG. **11**G illustrates an example block diagram of a PPG sensor which has the features of the PPG sensors shown in FIGS. **11**A-KKF.

FIG. **12**A illustrates an example of a portable biometric monitoring device having a heart rate or PPG sensor, motion sensor, display, vibromotor, and communication circuitry which is connected to a processor.

FIG. **12**B illustrates an example of a portable biometric monitoring device having a heart rate or PPG sensor, motion sensor, display, vibromotor, location sensor, altitude sensor, skin conductance/wet sensor and communication circuitry which is connected to a processor.

FIG. **12**C illustrates an example of a portable biometric monitoring device having physiological sensors, environmental sensors, and location sensors connected to a processor.

FIG. **13**A illustrates an example of the use of a motion signal and an optical PPG signal to measure a heart rate.

FIG. **13**B illustrates another example of the use of a motion signal and an optical PPG signal to measure heart rate.

FIG. **14**A illustrates an example of a sensor which has an analog connection to a sensor processor.

FIG. **14**B illustrates an example of a sensor which has an analog connection to a sensor processor which, in turn, has a digital connection to an application processor.

FIG. **14**C illustrates an example of a sensor device which has one or multiple sensors connected to an application processor.

FIG. **14**D illustrates an example of a sensor device which has one or multiple sensors connected to sensor processors which, in turn, are connected to an application processor.

FIG. **15**A illustrates an example of a swim detection algorithm using a sequential algorithm flow.

FIG. **15**B illustrates an example of a swim detection algorithm which uses a parallel algorithm flow.

FIG. **15**C illustrates an example of a swim detection algorithm which uses a hybrid of sequential and parallel algorithm flow.

FIG. **15**D illustrates an example of a swim detection algorithm which uses a hybrid of sequential and parallel algorithm flow.

FIG. **16**A illustrates an example schematic of a sample-and-hold circuit and differential/instrumentation amplifier which may be used in PPG sensing.

FIG. **16**B illustrates an example schematic of a circuit for a PPG sensor using a controlled current source to offset "bias" current prior to a transimpedance amplifier

FIG. **16**C illustrates an example schematic of a circuit for a PPG sensor using a sample-and-hold circuit for current feedback applied to photodiode (prior to a transimpedance amplifier).

FIG. **16**D illustrates an example schematic of a circuit for a PPG sensor using a differential/instrumentation amplifier with ambient light cancellation functionality.

FIG. **16**E illustrates an example schematic of a circuit for a PPG sensor using a photodiode offset current generated dynamically by a DAC.

FIG. **16**F illustrates an example schematic of a circuit for a PPG sensor using a photodiode offset current generated dynamically by a controlled voltage source.

FIG. **16**G illustrates an example schematic of a circuit for a PPG sensor including ambient light removal functionality using a "switched capacitor" method.

FIG. **16**H illustrates an example schematic of a circuit for a PPG sensor that uses a photodiode offset current generated by a constant current source (this may also be done using a constant voltage source and a resistor).

FIG. **16**I illustrates an example schematic of a circuit for a PPG sensor that includes ambient light removal functionality and differencing between consecutive samples.

FIG. **16**J illustrates an example schematic of a circuit for ambient light removal and differencing between consecutive samples.

FIG. **17**A shows a schematic diagram of a process that uses a light probing mechanism to determine whether the heart rate monitor is worn ("on-wrist") or unworn ("off-wrist").

FIG. **17**B shows a schematic diagram of a process that uses separate light probing mechanisms for off-wrist detection to exit PPG heart rate monitoring and for on-wrist detection to enter PPG heart rate monitoring.

FIG. **18**A shows a process flowchart for a wearable fitness monitoring device having the heart rate monitor operates in different modes in energy efficient ways according to some embodiments.

FIG. **18**B shows another process flowchart for operating a wearable fitness monitoring device having a heart rate monitor according to some embodiments starting with concurrent operation of a first mode for detecting heart signals and a second mode for detecting an unworn state.

FIG. **18**C shows a cartoon of light pulses that are used to provide data for heart rate vs. the light pulses for probing proximity of the user's body in some embodiments.

FIG. **18**D shows another cartoon of light pulses that can be used to provide data for heart rate vs. the light pulses for probing proximity of the user's body in some embodiments.

FIG. **19**A shows two relationship between light intensity emitted by a light source of a heart rate monitor vs. the signal detected by a photodetector of the heart rate monitor.

FIG. **19**B depicts the temporal modulation of the TIA signal as a result of heart beats.

FIG. **19**C shows flowchart for a process of operating a heart rate monitor of a wearable fitness monitoring device by adjusting light emission power and/or light detection gain of the heart rate monitor.

FIG. **19**D shows light pulse signal patterns that may be used to regulate a heart rate monitor's light source intensity and/or light detection gain.

FIGS. **19**E and **19**F respectively show linear and non-linear mathematical relationships between emitted intensity and detected intensity for different skin characteristics.

DETAILED DESCRIPTION

This disclosure is directed at biometric monitoring devices (which may also be referred to herein and in any references incorporated by reference as "wearable fitness monitoring device," "biometric tracking devices," "personal health monitoring devices," "portable monitoring devices," "portable biometric monitoring devices," "biometric monitoring devices," or the like), which may be generally described as wearable devices, typically of a small size, that are designed to be worn relatively continuously by a person. When worn, such biometric monitoring devices gather data regarding activities performed by the wearer or the wearer's physiological state. Such data may include data representative of the ambient environment around the wearer or the wearer's interaction with the environment, e.g., motion data regarding the wearer's movements, ambient light, ambient noise, air quality, etc., as well as physiological data obtained by measuring various physiological characteristics of the wearer, e.g., heart rate, perspiration levels, etc.

Biometric monitoring devices, as mentioned above, are typically small in size so as to be unobtrusive for the wearer. Fitbit offers several varieties of biometric monitoring devices that are all quite small and very light, e.g., the Fitbit Flex is a wristband with an insertable biometric monitoring device that is about 0.5" wide by 1.3" long by 0.25" thick. Biometric monitoring devices are typically designed to be able to be worn without discomfort for long periods of time and to not interfere with normal daily activity.

In some cases, a biometric monitoring device may leverage other devices external to the biometric monitoring device, e.g., an external heart rate monitor in the form of an EKG sensor on a chest strap may be used to obtain heart rate data or a GPS receiver in a smartphone may be used to obtain position data. In such cases, the biometric monitoring device may communicate with these external devices using wired or wireless communications connections. The concepts disclosed and discussed herein may be applied to both stand-alone biometric monitoring devices as well as biometric monitoring devices that leverage sensors or functionality provided in external devices, e.g., external sensors, sensors or functionality provided by smartphones, etc.

In general, the concepts discussed herein may be implemented in stand-alone biometric monitoring devices as well as, when appropriate, biometric monitoring devices that leverage external devices.

It is to be understood that while the concepts and discussion included herein are presented in the context of biometric monitoring devices, these concepts may also be applied in other contexts as well if the appropriate hardware is available. For example, many modern smartphones include motion sensors, such as accelerometers, that are normally included in biometric monitoring devices, and the concepts discussed herein may, if appropriate hardware is available in a device, be implemented in that device. In effect, this may be viewed as turning the smartphone into some form of biometric monitoring device (although one that is larger than a typical biometric monitoring device and that may not be worn in the same manner). Such implementations are also to be understood to be within the scope of this disclosure.

The functionality discussed herein may be provided using a number of different approaches. For example, in some implementations a processor may be controlled by computer-executable instructions stored in memory so as to provide functionality such as is described herein. In other implementations, such functionality may be provided in the form of an electrical circuit. In yet other implementations, such functionality may be provided by a processor or processors controlled by computer-executable instructions stored in a memory coupled with one or more specially-designed electrical circuits. Various examples of hardware that may be used to implement the concepts outlined herein include, but are not limited to, application specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), and general-purpose microprocessors coupled with memory that stores executable instructions for controlling the general-purpose microprocessors.

Standalone biometric monitoring devices may be provided in a number of form factors and may be designed to be worn in a variety of ways. In some implementations, a biometric monitoring device may be designed to be insertable into a wearable case or into multiple, different wearable cases, e.g., a wristband case, a belt-clip case, a pendant case, a case configured to be attached to a piece of exercise equipment such as a bicycle, etc. Such implementations are described in more detail in, for example, U.S. patent application Ser. No. 14/029,764, filed Sep. 17, 2013, which is hereby incorporated by reference for such purpose. In other implementations, a biometric monitoring device may be designed to be worn in only one manner, e.g., a biometric monitoring device that is integrated into a wristband in a non-removable manner may be intended to be worn only on a person's wrist (or perhaps ankle).

Portable biometric monitoring devices according to embodiments and implementations described herein may have shapes and sizes adapted for coupling to (e.g., secured to, worn, borne by, etc.) the body or clothing of a user. An example of a portable biometric monitoring devices is shown in FIG. **1**; the example portable monitoring device may have a user interface, processor, biometric sensor(s), memory, environmental sensor(s) and/or a wireless transceiver which may communicate with a client and/or server. An example of a wrist-worn portable biometric monitoring device is shown in FIGS. **2**A through **2**C. This device may have a display, button(s), electronics package, and/or an attachment band. The attachment band may be secured to the user through the use of hooks and loops (e.g., Velcro), a clasp, and/or a band having memory of its shape, e.g., through the use of a spring metal band. In FIG. **2**B, a sensor protrusion and recess for mating a charger and/or data transmission cable can be seen. In FIG. **2**C, a cross-section through the electronics package is shown. Of note are the sensor protrusion, main PCB board, and display.

Portable biometric monitoring devices may collect one or more types of physiological and/or environmental data from embedded sensors and/or external devices and communicate or relay such information to other devices, including devices capable of serving as an Internet-accessible data sources, thus permitting the collected data to be viewed, for example, using a web browser or network-based application. For example, while the user is wearing a biometric monitoring device, the biometric monitoring device may calculate and store the user's step count using one or more biometric sensors. The biometric monitoring device may then transmit data representative of the user's step count to an account on a web service (e.g., www.fitbit.com), computer, mobile phone, or health station where the data may be stored, processed, and visualized by the user. Indeed, the biometric monitoring device may measure or calculate a plurality of other physiological metrics in addition to, or in place of, the user's step count. These include, but are not limited to, energy expenditure, e.g., calorie burn, floors climbed and/or descended, heart rate, heart rate variability, heart rate recovery, location and/or heading, e.g., through GPS, GLONASS, or a similar system,

elevation, ambulatory speed and/or distance traveled, swimming lap count, swimming stroke type and count detected, bicycle distance and/or speed, blood pressure, blood glucose, skin conduction, skin and/or body temperature, muscle state measured via electromyography, brain activity as measured by electroencephalography, weight, body fat, caloric intake, nutritional intake from food, medication intake, sleep periods, e.g., clock time, sleep phases, sleep quality and/or duration, pH levels, hydration levels, respiration rate, and other physiological metrics. The biometric monitoring device may also measure or calculate metrics related to the environment around the user such as barometric pressure, weather conditions (e.g., temperature, humidity, pollen count, air quality, rain/snow conditions, wind speed), light exposure (e.g., ambient light, UV light exposure, time and/or duration spent in darkness), noise exposure, radiation exposure, and magnetic field. Furthermore, the biometric monitoring device or the system collecting the data streams from the biometric monitoring device may calculate metrics derived from such data. For example, the device or system may calculate the user's stress and/or relaxation levels through a combination of heart rate variability, skin conduction, noise pollution, and sleep quality. In another example, the device or system may determine the efficacy of a medical intervention, e.g., medication, through the combination of medication intake, sleep data, and/or activity data. In yet another example, the biometric monitoring device or system may determine the efficacy of an allergy medication through the combination of pollen data, medication intake, sleep and/or activity data. These examples are provided for illustration only and are not intended to be limiting or exhaustive. Further embodiments and implementations of sensor devices may be found in U.S. patent application Ser. No. 13/156,304, titled "Portable Biometric Monitoring Devices and Methods of Operating Same" filed Jun. 8, 2011 and U.S. Patent Application 61/680,230, titled "Fitbit Tracker" filed Aug. 6, 2012, which are both hereby incorporated herein by reference in their entireties.

Physiological Sensors

Biometric monitoring devices as discussed herein may use one, some or all of the following sensors to acquire physiological data, including, but not limited to, the physiological data outlined in the table below. All combinations and permutations of physiological sensors and/or physiological data are intended to fall within the scope of this disclosure. Biometric monitoring devices may include but are not limited to types of one, some, or all of the sensors specified below for the acquisition of corresponding physiological data; indeed, other type(s) of sensors may also or alternatively be employed to acquire the corresponding physiological data, and such other types of sensors are also intended to fall within the scope of the present disclosure. Additionally, the biometric monitoring device may derive the physiological data from the corresponding sensor output data, including but is not limited to the number or types of physiological data that it could derive from said sensor.

Physiological Sensors	Physiological data acquired
Optical Reflectometer	Heart Rate, Heart Rate Variability
Example Sensors:	SpO_2 (Saturation of Peripheral
Light emitter and receiver	Oxygen)
Multi or single LED and photo	Respiration
diode arrangement	Stress
Wavelength tuned for specific	Blood pressure
physiological signals	Arterial Stiffness
Synchronous detection/amplitude	Blood glucose levels
modulation	Blood volume
	Heart rate recovery
	Cardiac health
Motion Detector	Activity level detection
Example Sensors:	Sitting/standing detection
Inertial sensors, Gyroscopic sensors and/or	Fall detection
Accelerometers	
GPS	
Skin Temperature	Stress
EMG (eletromyographic sensor)	Muscle tension
EKG or ECG (electrocardiographic sensor)	Heart Rate
Example Sensors:	Heart Rate Variability
Single-lead ECG or EKG	Heart Rate Recovery
Dual-lead ECG or EKG	Stress
	Cardiac health
Magnetometer	Activity level based on rotation
Laser Doppler	
Power Meter	
Ultrasonic Sensor	Blood flow
Audio Sensor	Heart Rate
	Heart Rate Variability
	Heart Rate Recovery
	Laugh detection
	Respiration
	Respiration type, e.g., snoring, breathing,
	breathing problems (such as sleep apnea)
	User's voice
Strain gauge	Heart Rate
Example:	Heart Rate Variability
In a wrist band	Stress
Wet/Immersion Sensor	Stress
Example Sensor:	Swimming detection
Galvanic skin response	Shower detection

In one example embodiment, the biometric monitoring device may include an optical sensor to detect, sense, sample and/or generate data that may be used to determine information representative of, for example, stress (or level thereof), blood pressure, and/or heart rate of a user. (See, for example, FIGS. **2**A through **3**C and **11**A through KKG). In such embodiments, the biometric monitoring device may include an optical sensor having one or more light sources (LED, laser, etc.) to emit or output light into the user's body, as well as light detectors (photodiodes, phototransistors, etc.) to sample, measure and/or detect a response or reflection of such light from the user's body and provide data used to determine data that is representative of stress (or level thereof), blood pressure, and/or heart rate of a user (e.g., such as by using photoplethysmography).

In one example embodiment, a user's heart rate measurement may be triggered by criteria determined by one or more sensors (or processing circuitry connected to them). For instance, when data from a motion sensor(s) indicates a period of stillness or of little motion, the biometric monitoring device may trigger, acquire, and/or obtain a heart rate measurement or data. (See, for example, FIGS. **9**, **12**A, and **12**B).

FIG. **12**A illustrates an example of a portable biometric monitoring device having a heart rate or PPG sensor, motion sensor, display, vibromotor, and communication circuitry which is connected to a processor.

FIG. **12**B illustrates an example of a portable biometric monitoring device having a heart rate or PPG sensor, motion sensor, display, vibromotor, location sensor, altitude sensor, skin conductance/wet sensor and communication circuitry which is connected to a processor.

In one embodiment, when the motion sensor(s) indicate user activity or motion (for example, motion that is not suitable or optimum to trigger, acquire, and/or obtain desired heart rate measurement or data (for example, data used to determine a user's resting heart rate)), the biometric monitoring device and/or the sensor(s) employed to acquire and/or obtain a desired heart rate measurement or data may be placed in, or remain in, a low power state. Since heart rate measurements taken during motion may be less reliable and may be corrupted by motion artifacts, it may be desirable to decrease the frequency with which heart rate data samples are collected (thus decreasing power usage) when the biometric monitoring device is in motion.

In another embodiment, a biometric monitoring device may employ data (for example, from one or more motion sensors) indicative of user activity or motion to adjust or modify characteristics of triggering, acquiring, and/or obtaining desired heart rate measurements or data (for example, to improve robustness to motion artifact). For instance, if the biometric monitoring device receives data indicative of user activity or motion, the biometric monitoring device may adjust or modify the sampling rate and/or resolution mode of sensors used to acquire heart rate data (for example, where the amount of user motion exceeds a certain threshold, the biometric monitoring device may increase the sampling rate and/or increase the sampling resolution mode of sensors employed to acquire heart rate measurement or data.) Moreover, the biometric monitoring device may adjust or modify the sampling rate and/or resolution mode of the motion sensor(s) during such periods of user activity or motion (for example, periods where the amount of user motion exceeds a certain threshold). In this way, when the biometric monitoring device determines or detects such user activity or motion, the biometric monitoring device may place the motion sensor(s) into a higher sampling rate and/or higher sampling resolution mode to, for example, enable more accurate adaptive filtering of the heart rate signal. (See, for example, FIG. **9**).

FIG. **9** illustrates an example of a portable biometric monitoring device that changes how it detects a user's heart rate based on how much movement the biometric monitoring device is experiencing. In the case where there is motion detected (e.g., through the use of an accelerometer), the user may be considered by the biometric monitoring device to be "active" and high-sampling-rate heart rate detection may occur to reduce motion artifacts in the heart rate measurement. This data may be saved and/or displayed. In the case that the user is determined by the biometric monitoring device to not be moving (or to be relatively sedentary), low-sampling-rate heart rate detection (which does not consume as much power) may be adequate to measure a heart rate and may thus be used.

Notably, where a biometric monitoring device employs optical techniques to acquire heart rate measurements or data, e.g., by using photoplethysmography, a motion signal may be employed to determine or establish a particular approach or technique to data acquisition or measurement by the heart rate sensor (e.g., synchronous detection rather than a non-amplitude-modulated approach) and/or analysis thereof. (See, for example, FIG. **11**E). In this way, the data which is indicative of the amount of user motion or activity may cause the biometric monitoring device to establish or adjust the type or technique of data acquisition or measurement used by an optical heart rate sensor or sensors.

For example, in one embodiment, a biometric monitoring device (or heart-rate measurement technique as disclosed herein) may adjust and/or reduce the sampling rate of optical heart rate sampling when motion detector circuitry detects or determines that the biometric monitoring device wearer's motion is below a threshold (for example, if the biometric monitoring device determines the user is sedentary or asleep). (See, for example, FIG. **9**). In this way, the biometric monitoring device may control its power consumption. For example, the biometric monitoring device may reduce power consumption by reducing the sensor sampling rate—for instance, the biometric monitoring device may sample the heart rate (via the heart rate sensor) once every 10 minutes, or 10 seconds out of every 1 minute. Notably, the biometric monitoring device may, in addition thereto or in lieu thereof, control power consumption via controlling data processing circuitry analysis and/or data analysis techniques in accordance with motion detection. As such, the motion of the user may impact the heart rate data acquisition parameters and/or data analysis or processing thereof.

Motion Artifact Suppression in Heart Rate Sensors

As discussed above, the raw heart rate signal measured by a PPG sensor may be improved by using one or more algorithms to remove motion artifacts. Movement of the user (for determining motion artifacts) may be measured using sensors including, but not limited to, accelerometers, gyroscopes, proximity detectors, magnetometers, etc. The goal of such algorithms is to remove components os the PPG signal attributable to movement (movement artifacts) using the movement signal captured from the other sensors as a guide. In one embodiment the movement artifacts in the PPG signal may be removed using an adaptive filter based on a hybrid Kalman filter and a least mean square filter or a recursive least squares filter. The heart rate may then be extracted from the cleaned/filtered signal using a peak counting algorithm or a power spectral density estimation algorithm. Alternatively, a Kalman filter or particle filter may be used to remove such movement artifacts.

Another approach that may be used to calculate the heart rate frequency is to create a model of the heart rate signal as $Y=Y_{dc}+\Sigma a_k*\cos k\theta+b_k*\sin k\theta$, where k is the order of harmonic components, and θ is a model parameter for heart rate. This model may then be fit to the signal using either an extended Kalman filter or a particle filter. This model exploits the fact that the signal is not sinusoidal so contains power both at the fundamental harmonic as well as multiple additional harmonics.

Alternately, the signal may be modeled as $Y=Y_{dc}+\Sigma a_k*\sin(k*w_{motion}t+\theta)+\Sigma b_k*\sin(k*w_{HR}t+\varnothing)$, where w_{motion} is estimated directly from the accelerometer signal (or another motion sensor signal).

Ambient Light and Skin Color

Ambient light and skin color may make it difficult to extract a user's heart rate from a PPG signal. The effect of ambient light may be reduced by subtracting a value of the received detected light signal when the PPG light source is off from the value of the received detected light signal when the PPG light source is on (assuming that both signals are obtained in close temporal proximity to each other).

The effect of skin color may be reduced by changing the intensity of the PPG light source, the wavelength of the light emitted from the light source, and/or by using the ratio or difference of received signal corresponding to two different wavelengths. Skin color may be determined by using user input (e.g. the user entering their skin color), an image of the person's face, etc., and may then subsequently be used to calibrate the algorithm, light source brightness, light source wavelength, and the receiver gain. The effect of skin color (and tightness with which the user is wearing the device) on the raw PPG signal may also be measured by sending in a signal of known amplitude to the light source(s) and then measuring the received signal from the photodetector(s). Such a signal may be sent for a prolonged period of time (so as to capture data through multiple expected heart beats) and then averaged to produce a steady-state data set that is not heart-rate dependent. This amplitude may then be compared to a set of values stored in a table to determine algorithm calibration, transmitter amplitude and the receiver gain.

Heart Rate Estimate Improvement Using Heuristics

After getting an initial estimate of the heart rate (e.g. by peak counting of a power spectral density estimation), it may be useful to apply bounds on the allowable rates for heart rate. These bounds may be optimized on a per-user basis since each user will have a unique heart rate profile. For example, the sedentary rate of each user may be estimated when they are stationary and this may be used as a lower bound when the user is walking. Similarly, half the frequency of walking as calculated from the pedometer may serve as a good lower bound for the expected heart rate.

The heart rate algorithm may be tailored for each user and may learn the heart rate profile of the user and adapt to the user's behaviors and/or characteristics so as to perform better with time. For example, the algorithm may set bounds on the heart rate expected during a particular physical activity or rate of walking based on historical data from that user. This may help provide better results when the heart rate data is corrupted by noise and/or motion artifacts.

HR Quality Metric

In another example embodiment, a signal quality metric of the heart rate/PPG signal may be used to provide a quantification of the accuracy/precision of the signal being generated. Depending on the values of this metric, the algorithm that determines what the user's heart rate (or other PPG-derived metric such as respiration) is may take certain actions, including asking the user to tighten the watch band, ignoring certain portions of collected heart-rate data (e.g. sections of data that have a low quality metric), and weighting certain portions of the heart-rate data (e.g., data with a higher quality metric may be weighted more heavily when the heart rate is being calculated).

In one embodiment, the signal quality metric may be derived as follows: make a scatter plot where the x-axis is time, and the y-axis is the frequency of a peak in the PPG signal at that given instant in time. An issue to be overcome using this strategy is that there may be multiple and/or zero peaks at a given instant in time. A best fit line captures the linear relationship in this scatter plot. A high quality signal should have a set of peaks that fit well to a line (in a short time span), whereas a bad signal will have a set of peaks that are not well described by a line. Therefore, the quality of the fit to the line provides a good metric for the quality of the PPG signal itself.

Sedentary, Sleep, and Active Classified Metrics

In yet another example embodiment, the biometric monitoring device may employ sensors to calculate heart rate variability when the device determines the user to be sedentary or asleep. Here, the biometric monitoring device may operate the sensors in a higher-rate sampling mode (relative to non-sedentary periods or periods of user activity that exceed a predetermined threshold) to calculate heart rate variability. The biometric monitoring device (or an external device) may employ heart rate variability as an indicator of cardiac health or stress.

Indeed, in some embodiments, the biometric monitoring device may measure and/or determine the user's stress level and/or cardiac health when the user is sedentary and/or asleep (for example, as detected and/or determined by the biometric monitoring device). Some embodiments of a biometric monitoring device of the present disclosure may determine the user's stress level, health state (e.g., risk, onset, or progression of fever or cold), and/or cardiac health using sensor data that is indicative of the heart rate variability, galvanic skin response, skin temperature, body temperature, and/or heart rate. In this way, processing circuitry of the biometric monitoring device may determine and/or track the user's "baseline" stress levels over time and/or cardiac "health" over time. In another embodiment, the device may measure a physiologic parameter of the user during one or more periods where the user is motionless (or the user's motion is below a predetermined threshold), such as when the user is sitting, lying down, asleep, or in a sleep stage (e.g., deep sleep). Such data may also be employed by the biometric monitoring device as a "baseline" for stress-related parameters, health-related parameters (e.g., risk or onset of fever or cold), cardiac health, heart rate variability, galvanic skin response, skin temperature, body temperature and/or heart rate.

Sleep Monitoring

In some embodiments, the biometric monitoring device may automatically detect or determine when the user is attempting to go to sleep, is entering sleep, is asleep, and/or is awoken from a period of sleep. In such embodiments, the biometric monitoring device may employ physiological sensors to acquire data and the data processing circuitry of the biometric monitoring device may correlate a combination of heart rate, heart rate variability, respiration rate, galvanic skin response, motion, skin temperature, and/or body temperature data collected from sensors of the biometric monitoring device to detect or determine if the user is attempting to go to sleep, is entering sleep, is asleep, and/or is awoken from a period of sleep. In response, the biometric monitoring device may, for example, acquire physiological data (of the types, and in the manners, as described herein) and/or determine

physiological conditions of the user (of the types, and in the manners, as described herein). For example, a decrease or cessation of user motion combined with a reduction in user heart rate and/or a change in heart rate variability may indicate that the user has fallen asleep. Subsequent changes in heart rate variability and galvanic skin response may then be used by the biometric monitoring device to determine transitions of the user's sleep state between two or more stages of sleep (for example, into lighter and/or deeper stages of sleep). Motion by the user and/or an elevated heart rate and/or a change in heart rate variability may be used by the biometric monitoring device to determine that the user has awoken.

Real-time, windowed, or batch processing may be used to determine the transitions between wake, sleep, and sleep stages. For instance, a decrease in heart rate may be measured in a time window where the heart rate is elevated at the start of the window and reduced in the middle (and/or end) of the window. The awake and sleep stages may be classified by a hidden Markov model using changes in motion signal (e.g., decreasing motion intensity), heart rate, heart rate variability, skin temperature, galvanic skin response, and/or ambient light levels. The transition points may be determined through a changepoint algorithm (e.g., Bayesian changepoint analysis). The transition between awake and sleep may be determined by observing periods where the user's heart rate decreases over a predetermined time duration by at least a certain threshold but within a predetermined margin of the user's resting heart rate (that is observed as, for example, the minimum heart rate of the user while sleeping). Similarly, the transition between sleep and awake may be determined by observing an increase in the user's heart rate above a predetermined threshold of the user's resting heart rate.

In some embodiments, the biometric monitoring device may be one component of a system for monitoring sleep, where the system includes a secondary device configured to communicate with the biometric monitoring device and adapted to be placed near the sleeper (e.g., an alarm clock). The secondary device may, in some implementations, have a shape and mechanical and/or magnetic interface to accept the biometric monitoring device for safe keeping, communication, and/or charging. However, the secondary device may also be generic to the biometric monitoring device, e.g., a smartphone that is not specifically designed to physically interface with the biometric monitoring device. The communication between the biometric monitoring device and the secondary device may be provided through wired communication interfaces or through wireless communication interfaces and protocols such as Bluetooth (including, for example, Bluetooth 4.0 and Bluetooth Low Energy protocols), RFID, NFC, or WLAN. The secondary device may include sensors to assist in sleep monitoring or environmental monitoring such as, for example, sensors that measure ambient light, noise and/or sound (e.g., to detect snoring), temperature, humidity, and air quality (pollen, dust, CO_2, etc.). In one embodiment, the secondary device may communicate with an external service such as www.fitbit.com or a server (e.g., a personal computer). Communication with the secondary device may be achieved through wired (e.g., Ethernet, USB) or wireless (e.g., WLAN, Bluetooth, RFID, NFC, cellular) circuitry and protocols to transfer data to and/or from the secondary device. The secondary device may also act as a relay to transfer data to and/or from the biometric monitoring device to and/or from an external service such as www.fitbit.com or other service (e.g., data such as news, social network updates, email, calendar notifications) or server (e.g., personal computer, mobile phone, tablet). Calculation of the user's sleep data may be performed on one or both devices or an external service (e.g., a cloud server) using data from one or both devices.

The secondary device may be equipped with a display to display data obtained by the secondary device or data transferred to it by the biometric monitoring device, the external service, or a combination of data from the biometric monitoring device, the secondary device, and/or the external service. For example, the secondary device may display data indicative of the user's heart rate, total steps for the day, activity and/or sleep goal achievement, the day's weather (measured by the secondary device or reported for a location by an external service), etc. In another example, the secondary device may display data related to the ranking of the user relative to other users, such as total weekly step count. In yet another embodiment, the biometric monitoring device may be equipped with a display to display data obtained by the biometric monitoring device, the secondary device, the external service, or a combination of the three sources. In embodiments where the first device is equipped with a wakeup alarm (e.g., vibramotor, speaker), the secondary device may act as a backup alarm (e.g., using an audio speaker). The secondary device may also have an interface (e.g., display and buttons or touch screen) to create, delete, modify, or enable alarms on the first and/or the secondary device.

Sensor-Based Standby Mode

In another embodiment, the biometric monitoring device may automatically detect or determine whether it is or is not attached to, disposed on, and/or being worn by a user. In response to detecting or determining that the biometric monitoring device is not attached to, disposed on, and/or being worn by a user, the biometric monitoring device (or selected portions thereof) may implement or be placed in a low power mode of operation—for example, the optical heart rate sensor and/or circuitry may be placed in a lower power or sleep mode. For example, in one embodiment, the biometric monitoring device may include one or more light detectors (photodiodes, phototransistors, etc.). If, at a given light intensity setting (for example, with respect to the light emitted by a light source that is part of the biometric monitoring device), one or more light detectors provides a low return signal, the biometric monitoring device may interpret the data as indicative of the device not being worn. Upon such a determination, the device may reduce its power consumption—for example, by "disabling" or adjusting the operating conditions of the stress and/or heart rate detection sensors and/or circuitry in addition to other device circuitry or displays (for example, by reducing the duty cycle of or disabling the light source(s) and/or detector(s), turning off the device display, and/or disabling or attenuating associated circuitry or portions thereof). In addition, the biometric monitoring device may periodically determine (e.g., once per second) if the operating conditions of the stress and/or heart rate detection sensors and/or associated circuitry should be restored to a normal operating condition (for example, light source(s), detector(s) and/or associated circuitry should return to a normal operating mode for heart rate detection). In another embodiment, the biometric monitoring device may restore the operating conditions of the stress and/or heart rate detection sensors and/or associated circuitry upon detection of a triggerable event—for example, upon detecting motion of the device (for example, based on data from one or more motion sensor(s)) and/or detecting a user input via the user interface (for example, a tap, bump or swipe interaction with the biometric monitoring device). In some related embodiments, the biometric monitoring device may, for power saving purposes, reduce its default rate of heart rate measurement collection to, for instance, one mea-

surement per minute while the user is not highly active and the user may have the option of putting the device into a mode of operation to generate measurements on demand or at a faster rate (e.g., once per second), for instance, by pushing a button.

Optical Sensor(s)

In one embodiment, the optical sensors (sources and/or detectors) may be disposed on an interior or skin-side of the biometric monitoring device (i.e., a side of the biometric monitoring device that contacts, touches, and/or faces the skin of the user (hereinafter "skin-side")). (See, for example, FIGS. **2**A through **3**C). In another embodiment, the optical sensors may be disposed on one or more sides of the device, including the skin-side and one or more sides of the device that face or are exposed to the ambient environment (environmental side). (See, for example, FIGS. **6**A through **7**).

FIG. **6**A illustrates an example of a portable monitoring device having a band; optical sensors and light emitters may be placed on the band.

FIG. **6**B illustrates an example of a portable biometric monitoring device having a display and wristband. Additionally, optical PPG (e.g., heart rate) detection sensors and/or emitters may be located on the side of the biometric monitoring device. In one embodiment, these may be located in side-mounted buttons.

FIG. **7** depicts a user pressing the side of a portable biometric monitoring device to take a heart rate measurement from a side-mounted optical heart rate detection sensor. The display of the biometric monitoring device may show whether or not the heart rate has been detected and/or display the user's heart rate.

Notably, the data from such optical sensors may be representative of physiological data and/or environmental data. Indeed, in one embodiment, the optical sensors provide, acquire and/or detect information from multiple sides of the biometric monitoring device whether or not the sensors are disposed on one or more of the multiple sides. For example, the optical sensors may obtain data related to the ambient light conditions of the environment.

Where optical sensors are disposed or arranged on the skin-side of the biometric monitoring device, in operation, a light source in the biometric monitoring device may emit light upon the skin of the user and, in response, a light detector in the biometric monitoring device may sample, acquire, and/or detect corresponding reflected and/or emitted light from the skin (and from inside the body). The one or more light sources and light detectors may be arranged in an array or pattern that enhances or optimizes the signal-to-noise ratio and/or serves to reduce or minimize power consumption by the light sources and light detectors. These optical sensors may sample, acquire and/or detect physiological data which may then be processed or analyzed (for example, by resident processing circuitry) to obtain data that is representative of, for example, a user's heart rate, respiration, heart rate variability, oxygen saturation (SpO_2), blood volume, blood glucose, skin moisture, and/or skin pigmentation level.

The light source(s) may emit light having one or more wavelengths that are specific or directed to a type of physiological data to be collected. Similarly, the optical detectors may sample, measure and/or detect one or more wavelengths that are also specific or directed to a type of physiological data to be collected and/or a physiological parameter (of the user) to be assessed or determined. For instance, in one embodiment, a light source emitting light having a wavelength in the green spectrum (for example, an LED that emits light having wavelengths corresponding to the green spectrum) and a photodiode positioned to sample, measure, and/or detect a response or reflection corresponding with such light may provide data that may be used to determine or detect heart rate. In contrast, a light source emitting light having a wavelength in the red spectrum (for example, an LED that emits light having wavelengths corresponding to the red spectrum) and a light source emitting light having a wavelength in the infrared spectrum (for example, an LED that emits light having wavelengths corresponding to the IR spectrum) and photodiode positioned to sample, measure and/or detect a response or reflection of such light may provide data used to determine or detect SpO_2.

Indeed, in some embodiments, the color or wavelength of the light emitted by the light source, e.g., an LED (or set of LEDs), may be modified, adjusted, and/or controlled in accordance with a predetermined type of physiological data being acquired or conditions of operation. Here, the wavelength of the light emitted by the light source may be adjusted and/or controlled to optimize and/or enhance the "quality" of the physiological data obtained and/or sampled by the detector. For example, the color of the light emitted by the LED may be switched from infrared to green when the user's skin temperature or the ambient temperature is cool in order to enhance the signal corresponding to cardiac activity. (See, for example, FIG. **11**D).

The biometric monitoring device, in some embodiments, may include a window (for example, a window that is, to casual inspection, opaque) in the housing to facilitate optical transmission between the optical sensors and the user. Here, the window may permit light (for example, of a selected wavelength) to be emitted by, for example, one or more LEDs, onto the skin of the user and a response or reflection of that light to pass back through the window to be sampled, measured, and/or detected by, for example, one or more photodiodes. In one embodiment, the circuitry related to emitting and receiving light may be disposed in the interior of the device housing and underneath or behind a plastic or glass layer (for example, painted with infrared ink) or an infrared lens or filter that permits infrared light to pass but not light in the human visual spectrum. In this way, the light transmissivity of the window may be invisible to the human eye.

The biometric monitoring device may employ light pipes or other light-transmissive structures to facilitate transmission of light from the light sources to the user's body and skin. (See, for example, FIGS. **4**A through **5**). In this regard, in some embodiments, light may be directed from the light source to the skin of the user through such light pipes or other light-transmissive structures. Scattered light from the user's body may be directed back to the optical circuitry in the biometric monitoring device through the same or similar structures. Indeed, the light-transmissive structures may employ a material and/or optical design to facilitate low light loss (for example, the light-transmissive structures may include a lens to facilitate light collection, and portions of the light-transmissive structures may be coated with or adjacent to reflective materials to promote internal reflection of light within the light-transmissive structures) thereby improving the signal-to-noise-ratio of the photo detector and/or facilitating reduced power consumption of the light source(s) and/or light detectors. In some embodiments, the light pipes or other light-transmissive structures may include a material that selectively transmits light having one or more specific or predetermined wavelengths with higher efficiency than others, thereby acting as a bandpass filter. Such a bandpass filter may be tuned to improve the signal of a specific physiological data type. For example, in one embodiment, an In-Mold-Labeling or "IML" light-transmissive structure may be implemented where the light-transmissive structure uses a material with predetermined or desired optical characteristics

to create a specific bandpass characteristic, for example, so as to pass infrared light with greater efficiency than light of other wavelengths (for example, light having a wavelength in human visible spectrum). In another embodiment, a biometric monitoring device may employ a light-transmissive structure having an optically opaque portion (including certain optical properties) and an optically-transparent portion (including optical properties different from the optically-opaque portion). Such a light-transmissive structure may be provided via a double-shot or two-step molding process where optically opaque material and optically transparent material are separately injected into a mold. A biometric monitoring device implementing such a light-transmissive structure may include different light transmissivity properties for different wavelengths depending on the direction of light travel through the light-transmissive structure. For example, in one embodiment, the optically-opaque material may be reflective to a specific wavelength range so as to more efficiently transport light from the user's body back to the light detector (which may be of a different wavelength(s) relative to the wavelength(s) of the emitted light).

In another embodiment, reflective structures may be placed in the field of view of the light emitter(s) and/or light detector(s). For example, the sides of holes that channel light from light emitter(s) to a user's skin and/or from the user's skin to light detector(s) (or through which light-transmissive structures that perform such channeling travel) may be covered in a reflective material (e.g., chromed) to facilitate light transmission. The reflective material may increase the efficiency with which the light is transported to the skin from the light source(s) and then from the skin back into the detector(s). The reflectively-coated hole may be filled in with an optical epoxy or other transparent material to prevent liquid from entering the device body while still allowing light to be transmitted with low transmission loss.

In another embodiment that implements light-transmissive structures (for example, structures created or formed through IML), such light-transmissive structures may include a mask consisting of an opaque material that limits the aperture of one, some, or all of the light source(s) and/or detector(s). In this way, the light-transmissive structures may selectively "define" a preferential volume of the user's body that light is emitted into and/or detected from. Notably, other mask configurations may be employed or implemented in connection with the concepts described and/or illustrated herein; all such masking configurations to, for example, improve the photoplethysmography signal and which are implemented in connection with the concepts described and/or illustrated herein are intended to fall within the scope of the present disclosure.

In another embodiment, the light emitter(s) and/or detector(s) may be configured to transmit light through a hole or series of holes in the device exterior. This hole or series of holes may be filled in with light-transmissive epoxy (e.g. optical epoxy). The epoxy may form a light pipe that allows light to be transmitted from the light emitter(s) to the skin and from the skin back into the light detector(s). This technique also has the advantage that the epoxy may form a watertight seal, preventing water, sweat or other liquid from entering the device body though the hole(s) on the device exterior that allow the light emitter(s) and detector(s) to transmit to, and receive light from, the biometric monitoring device body exterior. An epoxy with a high thermal conductivity may be used to help prevent the light source(s) (e.g., LED's) from overheating.

In any of the light-transmissive structures described herein, the exposed surfaces of the optics (light-transmissive structures) or device body may include a hard coat paint, hard coat dip, or optical coatings (such as anti-reflection, scratch resistance, anti-fog, and/or wavelength band block (such as ultraviolet light blocking) coatings). Such characteristics or materials may improve the operation, accuracy and/or longevity of the biometric monitoring device.

FIG. **4**A illustrates an example of one potential PPG light source and photodetector geometry. In this embodiment, two light sources are placed on either side of a photodetector. These three devices are located in a protrusion on the back of a wristband-type biometric monitoring device (the side which faces the skin of the user).

FIGS. **4**B and **4**C illustrate examples of a PPG sensor having a photodetector and two LED light sources. These components are placed in a biometric monitoring device that has a protrusion on the back side. Light pipes optically connect the LEDs and photodetector with the surface of the user's skin. Beneath the skin, the light from the light sources scatters off of blood in the body, some of which may be scattered or reflected back into the photodetector.

FIG. **5** Illustrates an example of a biometric monitoring device with an optimized PPG detector that has a protrusion with curved sides so as not to discomfort the user. Additionally, the surface of light pipes that optically couple the photodetector and the LEDs to the wearer's skin are contoured to maximize light flux coupling between the LEDs and photodetectors and the light pipes. The ends of the light pipes that face the user's skin are also contoured. This contour may focus or defocus light to optimize the PPG signal. For example, the contour may focus emitted light to a certain depth and location that coincides with an area where blood flow is likely to occur. The vertex of these foci may overlap or be very close together so that the photodetector receives the maximum possible amount of scattered light.

In some embodiments, the biometric monitoring device may include a concave or convex shape, e.g., a lens, on the skin-side of the device, to focus light towards a specific volume at a specific depth in the skin and increase the efficiency of light collected from that point into the photodetector. (See, for example, FIGS. **4**A through **5**). Where such a biometric monitoring device also employs light pipes to selectively and controllably route light, it may be advantageous to shape the end of the light pipe with a degree of cylindricity, e.g., the end of the light pipe may be a be a cylindrical surface (or portion thereof) defined by a cylinder axis that is nominally parallel to the skin-side (for example, rather than use an axially-symmetric lens). For example, in a wristband-style biometric monitoring device, such a cylindrical lens may be oriented such that the cylinder axis is nominally parallel to the wearer's forearm, which may have the effect of limiting the amount of light that enters such a lens from directions parallel to the person's forearm and increasing the amount of light that enters such a lens from directions perpendicular to the person's forearm—since ambient light is more likely to reach the sensor detection area from directions that are not occluded by the straps of the biometric monitoring device, i.e., along the user's forearm axis, than from directions that are occluded by the straps, i.e., perpendicular to the user's forearm. Such a configuration may improve the signal-to-noise-ratio by increasing the efficiency of light transferred from the emitter onto or into the skin of the user while decreasing "stray" light from being detected or collected by the photodetector. In this way, the signal sampled, measured and/or detected by the photodetector consists less of stray light and more of the user's skin/body response to such emitted light (signal or data that is representative of the response to the emitted light).

In another embodiment, light-transmissive epoxy may be molded into a concave or convex shape so as to provide

beneficial optical properties to sensors as well. For example, during the application of light transmissive epoxy, the top of the light-transmissive structure that is formed by the epoxy may be shaped into a concave surface so that light couples more effectively into the light-transmissive structure.

In one embodiment, the components of the optical sensor may be positioned on the skin-side of the device and arranged or positioned to reduce or minimize the distance between (i) the light source(s) and/or the associated detector(s) and (ii) the skin of the user. See, for example, FIG. **3**A, which provides a cross-sectional view of a sensor protrusion of an example portable monitoring device. In FIG. **3**A, two light sources (e.g., LEDs) are placed on either side of a photodetector to enable PPG sensing. A light-blocking material is placed between the light sources and the photodetector to prevent any light from the light sources from reaching photodetector without first exiting the body of the biometric monitoring device. A flexible transparent layer may be placed on the lower surface of the sensor protrusion to form a seal. This transparent layer may serve other functions such as preventing liquid from entering the device where the light sources or photodetectors are placed. This transparent layer may be formed through in-mold labeling or "IML". The light sources and photodetector may be placed on a flexible PCB.

Such a configuration may improve the efficiency of light flux coupling between the components of the optical sensor and the user's body. For example, in one embodiment, the light source(s) and/or associated detector(s) may be disposed on a flexible or pliable substrate that may flex, allowing the skin-side of the biometric monitoring device, which may be made from a compliant material, to conform (for example, without additional processing) or be capable of being shaped (or compliant) to conform to the shape of the body part (for example, the user's wrist, arm, ankle, and/or leg) to which the biometric monitoring device is coupled to or attached during normal operation so that the light source(s) and/or associated detector(s) are/is close to the skin of the user (i.e., with little to no gap between the skin-side of the device and the adjacent surface of the skin of the user. See, for example, FIG. **6**A. In one embodiment, the light source(s) and/or associated detector(s) may be disposed on a Flat Flex Cable or "FFC" or flexible PCB. In this embodiment, the flexible or pliable substrate (for example, an FFC or flexible PCB) may connect to a second substrate (for example, PCB) within the device having other components disposed thereon (for example, the data processing circuitry). Optical components of differing heights may be mounted to different "fingers" of flexible substrate and pressed or secured to the housing surface such that the optical components are flush to the housing surface. In one embodiment, the second substrate may be a relatively inflexible or non-pliable substrate, fixed within the device, having other circuitry and components (passive and/or active) disposed thereon.

FIG. **3**B depicts a cross-sectional view of a sensor protrusion of an example portable monitoring device; this protrusion is similar to that presented in FIG. **3**A with the exception that the light sources and photodetector are placed on a flat and/or rigid PCB.

FIG. **3**C provides another cross-sectional view of an example PPG sensor implementation. Of note in this PPG sensor is the lack of a protrusion. Additionally, a liquid gasket and/or a pressure sensitive adhesive are used to prevent liquid from entering the biometric monitoring device body.

Some embodiments of biometric monitoring devices may be adapted to be worn or carried on the body of a user. In some embodiments including the optical heart rate monitor, the device may be a wrist-worn or arm-mounted accessory such as a watch or bracelet. (See, for example, FIGS. **2**A through **7**). In one embodiment, optical elements of the optical heart rate monitor may be located on the interior or skin-side of the biometric monitoring device, for example, facing the top of the wrist (i.e., the optical heart rate monitor may be adjacent to and facing the wrist) when the biometric monitoring device is worn on the wrist. (See, for example, FIGS. **2**A through **3**C).

In another embodiment, the optical heart rate monitor may be located on one or more external or environmental side surfaces of the biometric monitoring device. (See, for example, FIGS. **6**B and **7**). In such embodiments, the user may touch an optical window (behind which optical elements of the optical heart rate monitor are located) with a finger on the opposing hand to initiate a heart rate measurement (and/or other metrics related to heart rate such as heart rate variability) and/or collect data which may be used to determine the user's heart rate (and/or other metrics related to heart rate). (See, for example, FIG. **6**B). In one embodiment, the biometric monitoring device may trigger or initiate the measurement(s) by detecting a (sudden) drop in incident light on the photodiode—for example, when the user's finger is placed over the optical window. In addition thereto, or in lieu thereof, a heart rate measurement (or other such metric) may be trigged by an IR-based proximity detector and/or capacitive touch/proximity detector (which may be separate from other detectors). Such IR-based proximity detector and/or capacitive touch/proximity detector may be disposed in or on and/or functionally, electrically and/or physically coupled to the optical window to detect or determine the presence of, for example, the user's finger.

In yet another embodiment, the biometric monitoring device may include a button that, when depressed, triggers or initiates heart rate measurement (and/or other metrics related to heart rate). The button may be disposed in close proximity to the optical window to facilitate the user pressing the button while the finger is disposed on the optical window. (See, for example, FIG. **7**). In one embodiment, the optical window may be embedded in a push button. Thus, when the user presses the button, it may trigger a measurement of the finger that depresses the button. Indeed, the button may be given a shape and/or resistance to pressing that enhances or optimizes a pressure profile of the button against the finger to provide a high signal-to-noise-ratio during measurement or data acquisition. In other embodiments (not illustrated), the biometric monitoring device may take the form of a clip, a smooth object, a pendant, an anklet, a belt, etc. that is adapted to be worn on the body, clipped or mounted to an article of clothing, deposited in clothing (e.g., in a pocket), or deposited in an accessory (e.g., handbag).

In one specific embodiment, the biometric monitoring device may include a protrusion on the skin- or interior side of the device. (See, FIGS. **2**A through **6**A). When coupled to the user, the protrusion may engage the skin with more force than the surrounding device body. In this embodiment, an optical window or light transmissive structure (both of which are discussed in detail above) may form or be incorporated in a portion of the protrusion. The light emitter(s) and/or detector(s) of the optical sensor may be disposed or arranged in the protrusion near the window or light transmissive structure. (See, for example, FIGS. **2**B and **6**A). As such, when attached to the user's body, the window portion of the protrusion of the biometric monitoring device may engage the user's skin with more force than the surrounding device body—thereby providing a more secure physical coupling between the user's skin and the optical window. That is, the protrusion may cause sustained contact between the biometric monitoring device

and the user's skin that may reduce the amount of stray light measured by the photodetector, decrease relative motion between the biometric monitoring device and the user, and/or provide improved local pressure to the user's skin; all of which may increase the quality of the cardiac signal of interest. Notably, the protrusion may contain other sensors that benefit from close proximity and/or secure contact to the user's skin. These may be included in addition to or in lieu of a heart rate sensor and include sensors such as a skin temperature sensor (e.g., noncontact thermopile that utilizes the optical window or thermistor joined with thermal epoxy to the outer surface of the protrusion), pulse oximeter, blood pressure sensor, EMG, or galvanic skin response (GSR) sensor.

In addition thereto, or in lieu thereof, a portion of the skin-side of the biometric monitoring device may include a friction enhancing mechanism or material. For example, the skin-side of the biometric monitoring device may include a plurality of raised or depressed regions or portions (for example, small bumps, ridges, grooves, and/or divots). Moreover, a friction enhancing material (for example, a gel-like material such as silicone or other elastomeric material) may be disposed on the skin-side. Indeed, a device back made out of gel may also provide friction while also improving user comfort and preventing stray light from entering. As noted above, a friction-enhancing mechanism or material may be used alone or in conjunction with the biometric monitoring device having a protrusion as described herein. In this regard, the biometric monitoring device may include a plurality of raised or depressed regions or portions (for example, small bumps, ridges, grooves, and/or divots) in or on the protrusion portion of the device. Indeed, such raised or depressed regions or portions may be incorporated/embedded into or on a window portion of the protrusion. In addition thereto, or in lieu thereof, the protrusion portion may consist of or be coated with a friction enhancing material (for example, a gel-like material such as silicone). Notably, the use of a protrusion and/or friction may improve measurement accuracy of data acquisition corresponding to certain parameters (e.g., heart rate, heart rate variability, galvanic skin response, skin temperature, skin coloration, heat flux, blood pressure, blood glucose, etc.) by reducing motion of the biometric monitoring device (and thus of the sensor) relative to the user's skin during operation, especially while the user is in motion.

Some or all of the interior or skin-side housing of the biometric monitoring device may also consist of a metal material (for example, steel, stainless steel, aluminum, magnesium, or titanium). Such a configuration may provide a structural rigidity. (See, for example, FIG. **2**B). In such an embodiment, the device body may be designed to be hypoallergenic through the use of a hypoallergenic "nickel-free" stainless steel. Notably, it may be advantageous to employ (at least in certain locations) a type of metal that is at least somewhat ferrous (for example, a grade of stainless steel that is ferrous). In such embodiments, the biometric monitoring device (where it includes a rechargeable energy source (for example, rechargeable battery)) may interconnect with a charger via a connector that secures itself to the biometric monitoring device using magnets that couple to the ferrous material. In addition, biometric monitoring device may also engage a dock or dock station, using such magnetic properties, to facilitate data transfer. Moreover, such a housing may provide enhanced electromagnetic shielding that would enhance the integrity and reliability of the optical heart rate sensor and the heart rate data acquisition process/operation. Furthermore, a skin temperature sensor may be physically and thermally coupled, for example, with thermal epoxy, to the metal body to sense the temperature of the user. In embodiments including a protrusion, the sensor may be positioned near or in the protrusion to provide secure contact and localized thermal coupling to the user's skin.

In a preferred embodiment, one or more components of the optical sensor (which may, in one embodiment, be located in a protrusion, and/or in another embodiment, may be disposed or placed flush to the surface of the biometric monitoring device) are attached, fixed, included, and/or secured to the biometric monitoring device via a liquid-tight seal (i.e., a method/mechanism that prevents liquid ingress into the body of the biometric monitoring device). For example, in one embodiment, a device back made out of a metal such as, but not limited to, stainless steel, aluminum, magnesium, or titanium, or from a rigid plastic may provide a structure that is stiff enough to maintain the structural integrity of the device while accommodating a watertight seal for the sensor package. (See, for example, FIGS. **2**B through **3**C).

In a preferred embodiment, a package or module of the optical sensor may be connected to the device with a pressure-sensitive adhesive and a liquid gasket. See, for example, FIG. **3**C, which provides another cross-sectional view of a PPG sensor implementation. Of note in this PPG sensor is the lack of a protrusion. Additionally, a liquid gasket and/or a pressure sensitive adhesive are used to prevent liquid from entering the device body. Screws, rivets or the like may also be used, for example, if a stronger or more durable connection is required between the optical sensor package/module and the device body. Notably, the present embodiments may also use watertight glues, hydrophobic membranes such as Gore-Tex, o-rings, sealant, grease, or epoxy to secure or attach the optical sensor package/module to the biometric monitoring device body.

As discussed above, the biometric monitoring device may include a material disposed on the skin- or interior side that includes high reflectivity characteristics—for example, polished stainless steel, reflective paint, and polished plastic. In this way, light scattered off the skin-side of the device may be reflected back into the skin in order to, for example, improve the signal-to-noise-ratio of an optical heart rate sensor. Indeed, this effectively increases the input light signal as compared with a device body back that is non-reflective (or less reflective). Notably, in one embodiment, the color of the skin or interior side of the biometric monitoring device may be selected to provide certain optical characteristics (for example, reflect certain or predetermined wavelengths of light), in order to improve the signal with respect to certain physiological data types. For example, where the skin- or interior side of the biometric monitoring device is green, the measurements of the heart rate may be enhanced due to the preferential emission of a wavelength of the light corresponding to the green spectrum. Where the skin- or interior side of the biometric monitoring device is red, the measurements of the SpO2 may be enhanced due to the preferential emission of a wavelength of the light corresponding to the red spectrum. In one embodiment, the color of the skin- or interior side of the biometric monitoring device may be modified, adjusted and/or controlled in accordance with a predetermined type of physiological data being acquired.

FIG. **11**A depicts an example schematic block diagram of an optical heart rate sensor where light is emitted from a light source toward the user's skin and the reflection of such light from the skin/internal body of the user is sensed by a light detector, the signal from which is subsequently digitized by an analog to digital converter (ADC). The intensity of the light source may be modified (e.g., through a light source intensity control module) to maintain a desirable reflected signal intensity. For example, the light source intensity may

be reduced to avoid saturation of the output signal from the light detector. As another example, the light source intensity may be increased to maintain the output signal from the light detector within a desired range of output values. Notably, active control of the system may be achieved through linear or nonlinear control methods such as proportional-integral-derivative (PID) control, fixed step control, predictive control, neural networks, hysteresis, and the like, and may also employ information derived from other sensors in the device such as motion, galvanic skin response, etc. FIG. **11**A is provided for illustration and does not limit the implementation of such a system to, for instance, an ADC integrated within a MCU, or the use of a MCU for that matter. Other possible implementations include the use of one or more internal or external ADCs, FPGAs, ASICs, etc.

In another embodiment, system with an optical heart rate sensor may incorporate the use of a sample-and-hold circuit (or equivalent) to maintain the output of the light detector while the light source is turned off or attenuated to save power. In embodiments where relative changes in the light detector output are of primary importance (e.g., heart rate measurement), the sample-and-hold circuit may not have to maintain an accurate copy of the output of the light detector. In such cases, the sample-and-hold may be reduced to, for example, a diode (e.g., Schottky diode) and capacitor. The output of the sample-and-hold circuit may be presented to an analog signal conditioning circuit (e.g., a Sallen-Key bandpass filter, level shifter, and/or gain circuit) to condition and amplify the signal within frequency bands of interest (e.g., 0.1 Hz to 10 Hz for cardiac or respiratory function), which may then be digitized by the ADC. See, for example, FIG. **11**B.

In operation, circuit topologies such as those already described herein (e.g. a sample-and-hold circuit) remove the DC and low frequency components of the signal and help resolve the AC component related to heart rate and/or respiration. The embodiment may also include the analog signal conditioning circuitry for variable gain settings that can be controlled to provide a suitable signal (e.g., not saturated). The performance characteristics (e.g., slew rate and/or gain bandwidth product) and power consumption of the light source, light detector, and/or sample-and-hold may be significantly higher than the analog signal conditioning circuit to enable fast duty cycling of the light source. In some embodiments, the power provided to the light source and light detector may be controlled separately from the power provided to the analog signal conditioning circuit to provide additional power savings. Alternatively or additionally, the circuitry can use functionality such as an enable, disable and/or shutdown to achieve power savings. In another embodiment, the output of the light detector and/or sample-and-hold circuit may be sampled by an ADC in addition to or in lieu of the analog signal conditioning circuit to control the light intensity of the light source or to measure the physiologic parameters of interest when, for example, the analog signal conditioning circuit is not yet stable after a change to the light intensity setting. Notably, because the physiologic signal of interest is typically small relative to the inherent resolution of the ADC, in some embodiments, the reference voltages and/or gain of the ADC may be adjusted to enhance signal quality and/or the ADC may be oversampled. In yet another embodiment, the device may digitize the output of only the sample-and-hold circuit by, for example, oversampling, adjusting the reference voltages and/or gain of the ADC, or using a high resolution ADC. See, for example, FIG. **11**C.

PPG DC Offset Removal Techniques

In another embodiment, the sensor device may incorporate a differential amplifier to amplify the relative changes in the output of the light detector. See, for example, FIG. **11**F. In some embodiments, a digital average or digital low-pass filtered signal may be subtracted from the output of the light detector. This modified signal may then be amplified before it is digitized by the ADC. In another embodiment, an analog average or analog low-pass filtered signal may be subtracted from the output of the light detector through, for example, the use of a sample-and-hold circuit and analog signal conditioning circuitry. The power provided to the light source, light detector, and differential amplifier may be controlled separately from the power provided to the analog signal conditioning circuit to improve power savings.

In another embodiment, a signal (voltage or current, depending on the specific sensor implementation) may be subtracted from the raw PPG signal to remove any bias in the raw PPG signal and therefore increase the gain or amplification of the PPG signal that contains heart rate (or other circulatory parameters such as heart rate variability) information. This signal may be set to a default value in the factory, to a value based on the user's specific skin reflectivity, absorption, and/or color, and/or may change depending on feedback from an ambient light sensor, or depending on analytics of the PPG signal itself. For example, if the PPG signal is determined to have a large DC offset, a constant voltage may be subtracted from the PPG signal to remove the DC offset and enable a larger gain, therefore improving the PPG signal quality. The DC offset in this example may result from ambient light (for example from the sun or from indoor lighting) reaching the photodetector from or reflected light from the PPG light source.

In another embodiment, a differential amplifier may be used to measure the difference between current and previous samples rather than the magnitude of each signal. Since the magnitude of each sample is typically much greater than the difference between each sample, a larger gain can be applied to each measurement, therefore improving the PPG signal quality. The signal may then be integrated to obtain the original time domain signal.

In another embodiment, the light detector module may incorporate a transimpedance amplifier stage with variable gain. Such a configuration may avoid or minimize saturation from bright ambient light and/or bright emitted light from the light source. For example, the gain of the transimpedance amplifier may be automatically reduced with a variable resistor and/or multiplexed set of resistors in the negative feedback path of the transimpedance amplifier. In some embodiments, the device may incorporate little to no optical shielding from ambient light by amplitude-modulating the intensity of the light source and then demodulating the output of the light detector (e.g., synchronous detection). See, for instance, FIG. **11**E. In other aspects, if the ambient light is of sufficient brightness to obtain a heart rate signal, the light source may be reduced in brightness and/or turned off completely.

In yet another embodiment, the aforementioned processing techniques may be used in combination to optically measure physiological parameters of the user. See, for example, FIG. **11**G. This topology may allow the system to operate in a low power measurement state and circuit topology when applicable and adapt to a higher power measurement state and circuit topology as necessary. For instance, the system may measure the physiologic parameter (e.g., heart rate) of interest using analog signal-conditioning circuitry while the user is immobile or sedentary to reduce power consumption, but switch to oversampled sampling of the light detector output directly while the user is active.

In embodiments where the biometric monitoring device includes a heart rate monitor, processing of the signal to

obtain heart rate measurements may include filtering and/or signal conditioning such as band-pass filtering (e.g., Butterworth filter). To counteract large transients that may occur in the signal and/or to improve convergence of said filtering, nonlinear approaches may be employed such as neural networks or slew rate limiting. Data from the sensors on the device such as motion, galvanic skin response, skin temperature, etc., may be used to adjust the signal conditioning methods employed. Under certain operating conditions, the heart rate of the user may be measured by counting the number of signal peaks within a time window or by utilizing the fundamental frequency or second harmonic of the signal (e.g., through a fast Fourier transform (FFT)). In other cases, such as heart rate data acquired while the user is in motion, FFTs may be performed on the signal and spectral peaks extracted, which may then be subsequently processed by a multiple-target tracker which starts, continues, merges, and deletes tracks of the spectra. In some embodiments, a similar set of operations may be performed on the motion signal and the output may be used to do activity discrimination (e.g., sedentary, walking, running, sleeping, lying down, sitting, biking, typing, elliptical, weight training) which is used to assist the multiple-target tracker. For instance, it may be determined that the user was stationary and has begun to move. This information may be used to preferentially bias the track continuation toward increasing frequencies. Similarly, the activity discriminator may determine that the user has stopped running or is running slower and this information may be used to preferentially bias the track continuation toward decreasing frequencies. Tracking may be achieved with single-scan or multi-scan, multiple-target tracker topologies such as joint probabilistic data association trackers, multiple-hypothesis tracking, nearest neighbor, etc. Estimation and prediction in the tracker may be done through Kalman filters, spline regression, particle filters, interacting multiple model filters, etc. A track selector module may use the output tracks from the multiple-spectra tracker and estimate the user's heart rate. The estimate may be taken as the maximum likelihood track, a weight sum of the tracks against their probabilities of being the heart rate, etc. The activity discriminator may furthermore influence the selection and/or fusion to get the heart rate estimate. For instance, if the user is sleeping, sitting, lying down, or sedentary, a prior probability may be skewed toward heart rates in the 40-80 bpm range; whereas if the user is running, jogging, or doing other vigorous exercise, a prior probability may be skewed toward elevated heart rates in the 90-180 bpm range. The influence of the activity discriminator may be based on the speed of the user. The estimate may be shifted toward (or wholly obtained by) the fundamental frequency of the signal when the user is not moving. The track that corresponds to the user's heart rate may be selected based on criteria that are indicative of changes in activity; for instance, if the user begins to walk from being stationary, the track that illustrates a shift toward higher frequency may be preferentially chosen.

The acquisition of a good heart rate signal may be indicated to the user through a display on the biometric monitoring device or another device in wired or wireless communication with the biometric monitoring device (e.g., a Bluetooth Low Energy-equipped mobile phone). In some embodiments, the biometric monitoring device may include a signal-strength indicator that is represented by the pulsing of an LED viewable by the user. The pulsing may be timed or correlated to be coincident with the user's heartbeat. The intensity, pulsing rate and/or color of the LED may be modified or adjusted to suggest signal strength. For example, a brighter LED intensity may represent a stronger signal or in an RGB LED configuration, a green colored LED may represent a stronger signal.

In some embodiments, the strength of the heart rate signal may be determined by the energy (e.g., squared sum) of the signal in a frequency band of, for instance, 0.5 Hz to 4 Hz. In other embodiments, the biometric monitoring device may have a strain gauge, pressure sensor, force sensor, or other contact-indicating sensor that may be incorporated or constructed into the housing and/or in the band (in those embodiments where the biometric monitoring device is attached to or mounted with a band like a watch, bracelet, and/or armband—which may then be secured to the user). A signal quality metric (e.g. heart rate signal quality) may be calculated based on data from these contact sensors either alone or in combination with data from the heart rate signal.

In another embodiment, the biometric monitoring device may monitor heart rate optically through an array of photodetectors such as a grid of photodiodes or a CCD camera. Motion of the optical device with respect to the skin may be tracked through feature-tracking of the skin and/or adaptive motion correction using an accelerometer and gyroscope. The detector array may be in contact with the skin or offset at a small distance away from the skin. The detector array and its associated optics may be actively controlled (e.g., with a motor) to maintain a stabilized image of the target and acquire a heart rate signal. This optomechanical stabilization may be achieved using information from motion sensors (e.g., a gyroscope) or image features. In one embodiment, the biometric monitoring device may implement relative motion cancellation using a coherent or incoherent light source to illuminate the skin and a photodetector array with each photodetector associated with comparators for comparing the intensity between neighboring detectors—obtaining a so-called speckle pattern which may be tracked using a variety of image tracking techniques such as optical flow, template matching, edge tracking, etc. In this embodiment, the light source used for motion tracking may be different than the light source used in the optical heart rate monitor.

In another embodiment, the biometric monitoring device may consist of a plurality of photodetectors and photoemitters distributed along a surface of the device that touches the user's skin (i.e., the skin-side of the biometric monitoring device). (See, for example, FIGS. **2**A through **6**A). In the example of a bracelet, for instance, there may be a plurality of photodetectors and photoemitters placed at various sites along the circumference of the interior of the band. (See, for example, FIG. **6**A). A heart rate signal-quality metric associated with each site may be calculated to determine the best or set of best sites for estimating the user's heart rate. Subsequently, some of the sites may be disabled or turned off to, for example, reduce power consumption. The device may periodically check the heart rate signal quality at some or all of the sites to enhance, monitor and/or optimize signal and/or power efficiency.

In another embodiment, a biometric monitoring device may include a heart rate monitoring system including a plurality of sensors such as optical, acoustic, pressure, electrical (e.g., ECG or EKG), and motion and fuse the information from two or more of these sensors to provide an estimate of heart rate and/or mitigate noise induced from motion.

In addition to heart rate monitoring (or other biometric monitoring), or in lieu thereof, the biometric monitoring device, in some embodiments, may include optical sensors to track or detect time and duration of ultraviolet light exposure, total outdoor light exposure, the type of light source and duration and intensity of that light source (fluorescent light

exposure, incandescent bulb light exposure, halogen, etc.), exposure to television (based on light type and flicker rate), whether the user is indoors or outdoors, time of day and location based on light conditions. In one embodiment, the ultraviolet detection sensor may consist of a reverse biased LED emitter driven as a light detector. The photocurrent produced by this detector may be characterized by, for instance, measuring the time it takes for the LED's capacitance (or alternately a parallel capacitor) to discharge.

All of the optical sensors discussed herein may be used in conjunction with other sensors to improve detection of the data described above or be used to augment detection of other types of physiological or environmental data.

Where the biometric monitoring device includes an audio or passive acoustic sensor, the device may contain one or more passive acoustic sensors that detect sound and pressure and that can include, but are not limited to, microphones, piezo films, etc. The acoustic sensors may be disposed on one or more sides of the device, including the side that touches or faces the skin (skin-side) and the sides that face the environment (environmental sides).

Skin-side acoustic or audio sensors may detect any type of sound transmitted through the body and such sensors may be arranged in an array or pattern that optimizes both the signal-to-noise-ratio and power consumption of such sensors. These sensors may detect respiration (e.g., by listening to the lung), respiratory sounds (e.g., breathing, snoring) and problems (e.g., sleep apnea, etc.), heart rate (listening to the heart beat), user's voice (via sound transmitted from the vocal cords throughout the body).

The biometric monitoring devices of the present disclosure may also include galvanic skin-response (GSR) circuitry to measure the response of the user's skin to emotional and physical stimuli or physiological changes (e.g., the transition of sleep stage). In some embodiments, the biometric monitoring device may be a wrist- or arm-mounted device incorporating a band made of conductive rubber or fabric so that the galvanic skin response electrodes may be hidden in the band. Because the galvanic skin response circuitry may be subjected to changing temperatures and environmental conditions, it may also include circuitry to enable automatic calibration, such as two or more switchable reference resistors in parallel or in series with the human skin/electrode path that allows real-time measurement of known resistors to characterize the response of the galvanic skin response circuit. The reference resistors may be switched into and out of the measurement path such that they are measured independently and/or simultaneously with the resistance of the human skin.

Circuits for Performing PPG

PPG circuitry may be optimized to obtain the best quality signal regardless of a variety of environmental conditions including, but not limited to, motion, ambient light, and skin color. The following circuits and techniques may be used to perform such optimization (see FIGS. **16**A through **16**J);

- a sample-and-hold circuit and differential/instrumentation amplifier which may be used in PPG sensing. The output signal is an amplified difference between current and previous sample, referenced to a given voltage.
- controlled current source to offset "bias" current prior to transimpedance amplifier. This allows greater gain to be applied at transimpedance amplifier stage.
- a sample-and-hold circuit for current feedback applied to photodiode (prior to transimpedance amplifier). This can be used for ambient light removal, or "bias" current removal, or as a pseudo differential amplifier (may require dual rails).

- a differential/instrumentation amplifier with ambient light cancellation.
- a photodiode offset current generated dynamically by a DAC.
- a photodiode offset current generated dynamically by controlled voltage source.
- ambient light removal using a "switched capacitor" method.
- photodiode offset current generated by a constant current source (also can be done with a constant voltage source and a resistor).
- ambient light removal and differencing between consecutive samples.
- ambient light removal and differencing between consecutive samples.

FIG. **16**A illustrates an example schematic of a sample-and-hold circuit and differential/instrumentation amplifier which may be used in PPG sensing. The output signal in such a circuit may be an amplified difference between a current sample and a previous sample, referenced to a given voltage.

FIG. **16**B illustrates an example schematic of a circuit for a PPG sensor using a controlled current source to offset "bias" current prior to a transimpedance amplifier. This allows greater gain to be applied at the transimpedance amplifier stage.

FIG. **16**C illustrates an example schematic of a circuit for a PPG sensor using a sample-and-hold circuit for current feedback applied to photodiode (prior to a transimpedance amplifier). This circuit may be used for ambient light removal, or "bias" current removal, or as a pseudo-differential amplifier.

FIG. **16**D illustrates an example schematic of a circuit for a PPG sensor using a differential/instrumentation amplifier with ambient light cancellation functionality.

FIG. **16**E illustrates an example schematic of a circuit for a PPG sensor using a photodiode offset current generated dynamically by a DAC.

FIG. **16**F illustrates an example schematic of a circuit for a PPG sensor using a photodiode offset current generated dynamically by a controlled voltage source.

FIG. **16**G illustrates an example schematic of a circuit for a PPG sensor including ambient light removal functionality using a "switched capacitor" method.

FIG. **16**H illustrates an example schematic of a circuit for a PPG sensor that uses a photodiode offset current generated by a constant current source (this may also be done using a constant voltage source and a resistor).

FIG. **16**I illustrates an example schematic of a circuit for a PPG sensor that includes ambient light removal functionality and differencing between consecutive samples.

FIG. **16**J illustrates an example schematic of a circuit for ambient light removal and differencing between consecutive samples.

Various circuits and concepts related to heart rate measurement using a PPG sensor are discussed in more detail in U.S. Provisional Patent Application No. 61/946,439, filed Feb. 28, 2014, which was previously incorporated herein by reference in the "Cross-Reference to Related Applications" section and which is again hereby incorporated by reference with respect to content directed at heart rate measurements with a PPG sensor and at circuits, methods, and systems for performing such measurements, e.g., to compensate for sensor saturation, ambient light, and skin tone.

Biometric Feedback

Some embodiments of biometric monitoring devices may provide feedback to the user based on one or more biometric signals. In one embodiment, a PPG signal may be presented to the user as a real-time or near-real-time waveform on a dis-

play of the biometric monitoring device (or on a display of a secondary device in communication with the biometric monitoring device). This waveform may provide similar feedback to the waveform displayed on an ECG or EKG machine. In addition to providing the user with an indication of the PPG signal which may be used to estimate various heart metrics (e.g., heart rate), the waveform may also provide feedback that may enable the user to optimize the position and pressure with which they are wearing the biometric monitoring device. For example, the user may see that the waveform has a low amplitude. In response to this, the user may try moving the position of the biometric monitoring device to a different location which gives a higher amplitude signal. In some implementations, the biometric monitoring device may, based on such indications, provide instructions to the user to move or adjust the fit of the biometric monitoring device so as to improve the signal quality.

In another embodiment, feedback about the quality of the PPG signal may be provided to the user through a method other than displaying the waveform. The biometric monitoring device may emit an auditory alarm (e.g. a beep) if the signal quality (e.g. signal to noise ratio) exceeds a certain threshold. The biometric monitoring device may provide a visual cue (through the use of a display for example) to the user to either change the position of the sensor and/or increase the pressure with which the device is being worn (for example by tightening a wrist strap in the case that the device is worn on the wrist).

Biometric feedback may be provided for sensors other than PPG sensors. For example, if the device uses ECG, EMG, or is connected to a device which performs either of these, it may provide feedback to the user regarding the waveform from those sensors. If the signal-to-noise-ratio of these sensors is low, or the signal quality is otherwise compromised, the user may be instructed on how they can improve the signal. For example, if the heart rate cannot be detected from the ECG sensor, the device may provide a visual message to the user instructing them to wet or moisten the ECG electrodes to improve the signal.

Environmental Sensors

Some embodiments of biometric monitoring devices of the present disclosure may use one, some or all of the following environmental sensors to, for example, acquire the environmental data, including environmental data outlined in the table below. Such biometric monitoring devices are not limited to the number or types of sensors specified below but may employ other sensors that acquire environmental data outlined in the table below. All combinations and permutations of environmental sensors and/or environmental data are intended to fall within the scope of the present disclosure. Additionally, the device may derive environmental data from the corresponding sensor output data, but is not limited to the types of environmental data that it could derive from said sensor.

Notably, embodiments of biometric monitoring devices of the present disclosure may use one or more, or all of the environmental sensors described herein and one or more, or all of the physiological sensors described herein. Indeed, biometric monitoring device of the present disclosure may acquire any or all of the environmental data and physiological data described herein using any sensor now known or later developed—all of which are intended to fall within the scope of the present disclosure.

Environmental Sensors	Environmental data acquired
Motion Detector Potential Embodiments: Inertial, Gyroscopic or Accelerometer-based Sensors GPS	Location
Pressure/Altimeter sensor	Elevation
Ambient Temp	Temperature
Light Sensor	Indoor vs outdoor Watching TV (spectrum/flicker rate detection) Optical data transfer-initiation, QR codes, etc. Ultraviolet light exposure
Audio	Indoor vs. Outdoor
Compass Potential Embodiments: 3 Axis Compass	Location and/or orientation

In one embodiment, the biometric monitoring device may include an altimeter sensor, for example, disposed or located in the interior of the device housing. (See, for example, FIGS. **12**B and **12**C; FIG. **12**C illustrates an example of a portable biometric monitoring device having physiological sensors, environmental sensors, and location sensors connected to a processor). In such a case, the device housing may have a vent that allows the interior of the device to measure, detect, sample and/or experience any changes in exterior pressure. In one embodiment, the vent may prevent water from entering the device while facilitating measuring, detecting and/or sampling changes in pressure via the altimeter sensor. For example, an exterior surface of the biometric monitoring device may include a vent type configuration or architecture (for example, a Gore™ vent) that allows ambient air to move in and out of the housing of the device (which allows the altimeter sensor to measure, detect and/or sample changes in pressure), but reduces, prevents, and/or minimizes water and other liquids from flowing into the housing of the device.

The altimeter sensor, in one embodiment, may be filled with gel that allows the sensor to experience pressure changes outside of the gel. The gel may act as a relatively impervious, incompressible, yet flexible, membrane that transmits external pressure variations to the altimeter while physically separating the altimeter (and other internal components) from the outside environment. The use of a gel-filled altimeter may give the device a higher level of environmental protection with or without the use of an environmentally sealed vent. The device may have a higher survivability rate with a gel-filled altimeter in locations including, but not limited to, locations that have high humidity, clothes washers, dish washers, clothes dryers, a steam room or sauna, a shower, a pool, a bath, and any location where the device may be exposed to moisture, exposed to liquid, or submerged in liquid.

Sensors Integration/Signal Processing

Some embodiments of the biometric monitoring devices of the present disclosure may use data from two or more sensors to calculate the corresponding physiological or environmental data as seen in the table below (for example, data from two or more sensors may be used in combination to determine metrics such as those listed below). The biometric monitoring device may include, but is not limited to, the number, types, or combinations of sensors specified below. Additionally, such biometric monitoring devices may derive the included data from the corresponding sensor combinations, but are not limited to the number or types of data that may be calculated from the corresponding sensor combinations.

Sensor Integrations	Data derived from signal processing of multiple sensors
Skin Temp and Ambient Temp	Heat Flux
Heart Rate and Motion	Elevation gain
Motion detector and other user's motion detector (linked by wireless communication path)	Users in the proximity
Motion, any heart rate sensor, galvanic skin response	Sit/Standing detection
Any heart rate, heart rate variability sensor, respiration, motion	Sleep Phase detection Sleep Apnea detection
Any heart rate sensor and/or wetness sensor, and/or motion detector	Resting Heart rate Active Heart Rate Heart rate while asleep Heart rate while sedentary
Any heart rate detector	Early detection of heart problems: Cardiac Arrhythmia Cardiac Arrest
Multiple heart rate detectors	Pulse transit time
Audio and/or strain gauge	Typing detection
GPS and photoplethysmography (PPG)	Location-stress correlation: determination of stressful regions determination of low stress regions Activity specific heart rate resting heart rate active heart rate Automatic activity classification and activity heart rate determination
Heart rate, galvanic skin response, accelerometer and respiration	User fatigue, for example while exercising

In some embodiments, the biometric monitoring device may also include a near-field communication (NFC) receiver/transmitter to detect proximity to another device, such as a mobile phone. When the biometric monitoring device is brought into close or detectable proximity to the second device, it may trigger the start of new functionality on the second device (e.g., the launching of an "app" on the mobile phone and radio syncing of physiological data from the device to the second device). (See, for example, FIG. **10**). Indeed, the biometric monitoring device of the present disclosure may implement any of the circuitry and techniques described and/or illustrated in U.S. Provisional Patent Application 61/606,559, filed Mar. 5, 2012, "Near Field Communication System, and Method of Operating Same", inventor: James Park (the contents of which are incorporated herein by reference for such purpose).

FIG. **10** illustrates an example of a portable biometric monitoring device that has a bicycle application on it that may display bicycle speed and/or pedaling cadence, among other metrics. The app may be activated whenever the biometric monitoring device comes into proximity of a passive or active NFC tag. This NFC tag may be attached to the user's handlebars.

In another embodiment, the biometric monitoring device may include a location sensor (for example, GPS circuitry) and heart rate sensor (for example, photoplethysmography circuitry) to generate GPS- or location-related data and heart rate-related data, respectively. (See, for example, FIGS. **12**B and **12**C). The biometric monitoring device may then fuse, process and/or combine data from these two sensors/circuitries to, for example, determine, correlate, and/or "map" geographical regions according to physiological data (for example, heart rate, stress, activity level, quantity of sleep and/or caloric intake). In this way, the biometric monitoring device may identify geographical regions that increase or decrease a measurable user metric including, but not limited to, heart rate, stress, activity, level, quantity of sleep and/or caloric intake.

In addition thereto, or in lieu thereof, some embodiments of biometric monitoring devices may employ GPS-related data and photoplethysmography-related data (notably, each of which may be considered data streams) to determine or correlate the user's heart rate according to activity levels—for example, as determined by the user's acceleration, speed, location and/or distance traveled (as measured by the GPS and/or determined from GPS-related data). (See, for example, FIGS. **12**B and **12**C). Here, in one embodiment, heart rate as a function of speed may be "plotted" for the user, or the data may be broken down into different levels including, but not limited to, sleeping, resting, sedentary, moderately active, active, and highly active.

Indeed, some embodiments of biometric monitoring devices may also correlate GPS-related data to a database of predetermined geographic locations that have activities associated with them for a set of predetermined conditions. For example, activity determination and corresponding physiological classification (for example, heart rate classification) may include correlating a user's GPS coordinates that correspond to location(s) of exercise equipment, health club and/or gym and physiological data. Under these circumstances, a user's heart rate during, for example a gym workout, may be automatically measured and displayed. Notably, many physiological classifications may be based on GPS-related data including location, acceleration, altitude, distance and/or velocity. Such a database including geographic data and physiological data may be compiled, developed and/or stored on the biometric monitoring device and/or external computing device. Indeed, in one embodiment, the user may create their own location database or add to or modify the location database to better classify their activities.

In another embodiment, the user may simultaneously wear multiple biometric monitoring devices (having any of the features described herein). The biometric monitoring devices of this embodiment may communicate with each other or a remote device using wired or wireless circuitry to calculate, for example, biometric or physiologic qualities or quantities that, for example, may be difficult or inaccurate to calculate otherwise, such as pulse transit time. The use of multiple sensors may also improve the accuracy and/or precision of biometric measurements over the accuracy and/or precision of a single sensor. For example, having a biometric tracking device on the waist, wrist, and ankle may improve the detection of the user taking a step over that of a single device in only one of those locations. Signal processing may be performed on the biometric tracking devices in a distributed or centralized method to provide measurements improved over that of a single device. This signal processing may also be performed remotely and communicated back to the biometric tracking devices after processing.

In another embodiment, heart rate or other biometric data may be correlated to a user's food log (a log of foods ingested by a user, their nutritional content, and portions thereof). Food log entries may be entered into the food log automatically or may be entered by the user themselves through interaction with the biometric monitoring device (or a secondary or remote device, e.g., a smartphone, in communication with the biometric monitoring device or some other device, e.g., a server, in communication with the biometric monitoring device). Information may be presented to the user regarding the biometric reaction of their body to one or more food inputs. For example, if a user has coffee, their heart rate may rise as a result of the caffeine. In another example, if a user has a larger portion of food late at night, it may take longer for

them to fall asleep than usual. Any combination of food input and corresponding result in biometrics may be incorporated into such a feedback system.

The fusion of food intake data and biometric data may also enable some embodiments of biometric monitoring device to make an estimation of a user's glucose level. This may be particularly useful for users who have diabetes. With an algorithm which relates the glucose level to the user's activity (e.g. walking, running, calorie burn) and nutritional intake, a biometric monitoring device may be able to advise the user when they are likely to have an abnormal blood sugar level.

Processing Task Delegation

Embodiments of biometric monitoring devices may include one or more processors. For example, an independent application processor may be used to store and execute applications that utilize sensor data acquired and processed by one or more sensor processors (processor(s) that process data from physiological, environmental, and/or activity sensors). In the case where there are multiple sensors, there may also be multiple sensor processors. An application processor may have sensors directly connected to it as well. Sensor and application processors may exist as separate discrete chips or exist within the same packaged chip (multi-core). A device may have a single application processor, or an application processor and sensor processor, or a plurality of application processors and sensor processors.

In one embodiment, the sensor processor may be placed on a daughterboard that consists of all of the analog components. This board may have some of the electronics typically found on the main PCB such as, but not limited to, transimpedance amplifiers, filtering circuits, level shifters, sample-and-hold circuits, and a microcontroller unit. Such a configuration may allow the daughterboard to be connected to the main PCB through the use of a digital connection rather than an analog connection (in addition to any necessary power or ground connections). A digital connection may have a variety of advantages over an analog daughterboard to main PCB connection, including, but not limited to, a reduction in noise and a reduction in the number of necessary cables. The daughterboard may be connected to the main board through the use of a flex cable or set of wires.

Multiple applications may be stored on an application processor. An application may consist of executable code and data for the application, but is not limited to these. Data may consist of graphics or other information required to execute the application or it may be information output generated by the application. The executable code and data for the application may both reside on the application processor (or memory incorporated therein) or the data for the application may be stored and retrieved from an external memory. External memory may include but is not limited to NAND flash, NOR flash, flash on another processor, other solid-state storage, mechanical or optical disks, RAM, etc.

The executable code for an application may also be stored in an external memory. When a request to execute an application is received by the application processor, the application processor may retrieve the executable code and/or data from the external storage and execute it. The executable code may be temporarily or permanently stored on the memory or storage of the application processor. This allows the application to be executed more quickly on the next execution request, since the step of retrieval is eliminated. When the application is requested to be executed, the application processor may retrieve all of the executable code of the application or portions of the executable code. In the latter case, only the portion of executable code required at that moment is

retrieved. This allows applications that are larger than the application processor's memory or storage to be executed.

The application processor may also have memory protection features to prevent applications from overwriting, corrupting, interrupting, blocking, or otherwise interfering with other applications, the sensor system, the application processor, or other components of the system.

Applications may be loaded onto the application processor and/or any external storage via a variety of wired, wireless, optical, or capacitive mechanisms including, but not limited to, USB, Wi-Fi, Bluetooth, Bluetooth Low Energy, NFC, RFID, Zigbee.

Applications may also be cryptographically signed with an electronic signature. The application processor may restrict the execution of applications to those that have the correct signature.

Integration of Systems in a Biometric Monitoring Device

In some implementations of biometric monitoring devices, some sensors or electronic systems in the biometric monitoring device may be integrated with one another or may share components or resources. For example, a photodetector for an optically-based heart rate sensor (such as may be used in the heart-rate sensors discussed in U.S. Provisional Patent Application No. 61/946,439, filed Feb. 28, 2014, and previously incorporated by reference herein), may also serve as a photodetector for determining ambient light level, such as may be used to correct for the effects of ambient light on the heart rate sensor reading. For example, if the light source for such a heart rate detector is turned off, the light that is measured by the photodetector may be indicative of the amount of ambient light that is present.

In some implementations of a biometric monitoring device, the biometric monitoring device may be configured or communicated with using onboard optical sensors such as the components in an optical heart rate monitor. For example, the photodetectors of an optical heart-rate sensor (or, if present, an ambient light sensor) may also serve as a receiver for an optically-based transmission channel, e.g., infrared communications.

In some implementations of a biometric monitoring device, a hybrid antenna may be included that combines a radio frequency antenna, e.g., a Bluetooth antenna or GPS antenna, with an inductive loop, such as may be used in a near-field communications (NFC) tag or in an inductive charging system. In such implementations, the functionality for two different systems may be provided in one integrated system, saving packing volume. In such a hybrid antenna, an inductive loop may be placed in close proximity to the radiator of an inverted-F antenna. The inductive loop may inductively couple with the radiator, allowing the inductive loop to serve as a planar element of the antenna for radio-frequency purposes, thus forming, for example, a planar inverted-F antenna. At the same time, the inductive loop may also serve its normal function, e.g., such as providing current to an NFC chip through inductive coupling with an electromagnetic field generated by an NFC reader. Examples of such hybrid antenna systems are discussed in more detail in U.S. Provisional Patent Application No. 61/948,470, filed Mar. 5, 2014, which was previously incorporated herein by reference in the "Cross-Reference to Related Applications" section and which is again hereby incorporated by reference with respect to content directed at hybrid antenna structures. Of course, such hybrid antennas may also be used in other electronic devices other than biometric monitoring devices, and such non-biometric-monitoring-device use of hybrid antennas is contemplated as being within the scope of this disclosure.

Methods of Wearing the Device

Some embodiments of biometric monitoring devices may include a housing having a size and shape that facilitates fixing the biometric monitoring device to the user's body during normal operation where the device, when coupled to the user, does not measurably or appreciably impact the user's activity. The biometric monitoring device may be worn in different ways depending on the specific sensor package that is integrated into the biometric monitoring device and the data that the user would like to acquire.

A user may wear some embodiments of the biometric monitoring devices of the present disclosure on their wrist or ankle (or arm or leg) with the use of a band that is flexible and thereby readily fitted to the user. The band may have an adjustable circumference, therefore allowing it to be fitted to the user. The band may be constructed from a material that shrinks when exposed to heat, therefore allowing the user to create a custom fit. The band may be detachable from the "electronics" portion of the biometric monitoring device and, if necessary, replaceable.

In some embodiments, the biometric monitoring device may consist of two major components—a body (containing the "electronics") and a band (that facilitates attaching the device to the user). The body may include a housing (made, for example, of a plastic or plastic-like material) and extension tabs projecting from the body (made, for example, from a metal or metal-like material). (See, for example, FIGS. **2**C through **3**C). The band (made, for example, of a thermoplastic urethane) may be attachable to the body, e.g., mechanically or adhesively. The band may extend out a fraction of the circumference of the user's wrist. The distal ends of the urethane band may be connected with a Velcro or a hook-and-loop elastic fabric band that loops around a D-Ring on one side and then attaches back to itself. In this embodiment, the closure mechanism may allow the user infinite band length adjustment (unlike an indexed hole and mechanical clasp closure). The Velcro or elastic fabric may be attached to the band in a manner that allows it to be replaced (for example, if it is worn or otherwise undesirable to wear before the useful end of life of the device). In one embodiment, the Velcro or fabric may be attached with screws or rivets and/or glue, adhesives, and/or a clasp to the band.

Embodiments of the biometric monitoring devices of the present disclosure may also be integrated into and worn in a necklace, chest band, bra, adhesive patch, glasses, earring, or toe band. Such biometric monitoring devices may be built in such a way that the sensor package/portion of the biometric monitoring device is removable and may be worn in any number of ways including, but not limited to, those listed above.

In another embodiment, embodiments of biometric monitoring devices of the present disclosure may be worn clipped to an article of clothing or deposited in clothing (e.g., pocket) or an accessory (e.g., handbag, backpack, wallet). Because such biometric monitoring devices may not be near the user's skin, in embodiments that include heart rate measurements, the measurements may be obtained in a discrete, "on demand" context by the user manually placing the device into a specific mode (e.g., by depressing a button, covering a capacitive touch sensor with a fingertip, etc., possibly with the heart rate sensor embedded in the button/sensor) or automatically once the user places the device against the skin (e.g., applying the finger to an optical heart rate sensor).

User Interface with the Device

Some embodiments of a biometric monitoring device may include functionality for allowing one or more methods of interacting with the device either locally or remotely.

In some embodiments, the biometric monitoring device may convey data visually through a digital display. The physical embodiment of this display may use any one or a plurality of display technologies including, but not limited to one or more of LED, LCD, AMOLED, E-Ink, Sharp display technology, graphical displays, and other display technologies such as TN, HTN, STN, FSTN, TFT, IPS, and OLET. This display may show data acquired or stored locally on the device or may display data acquired remotely from other devices or Internet services. The biometric monitoring device may use a sensor (for example, an Ambient Light Sensor, "ALS") to control or adjust the amount of screen backlighting, if backlighting is used. For example, in dark lighting situations, the display may be dimmed to conserve battery life, whereas in bright lighting situations, the display brightness may be increased so that it is more easily read by the user.

In another embodiment, the biometric monitoring device may use single or multicolor LEDs to indicate a state of the device. States that the biometric monitoring device may indicate using LEDs may include, but are not limited to, biometric states such as heart rate or application states such as an incoming message or that a goal has been reached. These states may be indicated through the LED's color, the LED being on or off (or in an intermediate intensity), pulsing (and/or rate thereof) of the LEDs, and/or a pattern of light intensities from completely off to highest brightness. In one embodiment, an LED may modulate its intensity and/or color with the phase and frequency of the user's heart rate.

In some embodiments, the use of an E-Ink display may allow the display to remain on without the battery drain of a non-reflective display. This "always-on" functionality may provide a pleasant user experience in the case of, for example, a watch application where the user may simply glance at the biometric monitoring device to see the time. The E-Ink display always displays content without compromising the battery life of the device, allowing the user to see the time as they would on a traditional watch.

Some implementations of a biometric monitoring device may use a light such as an LED to display the heart rate of the user by modulating the amplitude of the light emitted at the frequency of the user's heart rate. The device may depict heart rate zones (e.g., aerobic, anaerobic, etc.) through the color of an LED (e.g., green, red) or a sequence of LEDs that light up in accordance with changes in heart rate (e.g., a progress bar). The biometric monitoring device may be integrated or incorporated into another device or structure, for example, glasses or goggles, or communicate with glasses or goggles to display this information to the user.

Some embodiments of a biometric monitoring device may also convey information to a user through the physical motion of the device. One such embodiment of a method to physically move the device is the use of a vibration-inducing motor. The device may use this method alone, or in combination with a plurality of other motion-inducing technologies.

In some implementations, a biometric monitoring device may convey information to a user through audio feedback. For example, a speaker in the biometric monitoring device may convey information through the use of audio tones, voice, songs, or other sounds.

These three information communication methods—visual, motion, and auditory—may, in various embodiments of biometric monitoring devices, be used alone or in any combination with each other or another method of communication to communicate any one or plurality of the following information:

That a user needs to wake up at certain time

That a user should wake up as they are in a certain sleep phase

That a user should go to sleep as it is a certain time

That a user should wake up as they are in a certain sleep phase and in a preselected time window bounded by the earliest and latest time that the user wants to wake up.

That an email was received

- That the user has been inactive for a certain period of time. Notably, this may integrate with other applications like, for instance, a meeting calendar or sleep tracking application to block out, reduce, or adjust the behavior of the inactivity alert.
- That the user has been active for a certain period of time
- That the user has an appointment or calendar event
- That the user has reached a certain activity metric
- That the user has gone a certain distance
- That the user has reached a certain mile pace
- That the user has reached a certain speed
- That the user has accumulated a certain elevation gain
- That the user has taken a certain number of steps
- That the user has had a heart rate measurement recently
- That the user's heart rate has reached a certain level
- That the user has a normal, active, or resting heart rate of a specific value or in a specific range
- That the user's heart rate has enter or exited a certain goal range or training zone
- That the user has a new heart rate "zone" goal to reach, as in the case of heart rate zone training for running, bicycling, swimming, etc. activities
- That the user has swum a lap or completed a certain number of laps in a pool
- An external device has information that needs to be communicated to the user such as an incoming phone call or any one of the above alerts
- That the user has reached a certain fatigue goal or limit. In one embodiment, fatigue may be determined through a combination of heart rate, galvanic skin response, motion sensor, and/or respiration data

These examples are provided for illustration and are not intended to limit the scope of information that may be communicated by such embodiments of biometric monitoring devices (for example, to the user). Note that the data used to determine whether or not an alert condition is met may be acquired from a first device and/or one or more secondary devices. The biometric monitoring device itself may determine whether the criteria or conditions for an alert have been met. Alternatively, a computing device in communication with the biometric monitoring device (e.g., a server and/or a mobile phone) may determine when the alert should occur. In view of this disclosure, other information that the biometric monitoring device may communicate to the user may be envisioned by one of ordinary skill in the art. For example, the biometric monitoring device may communicate with the user when a goal has been met. The criteria for meeting this goal may be based on physiological, contextual, and environmental sensors on a first device, and/or other sensor data from one or more secondary devices. The goal may be set by the user or may be set by the biometric monitoring device itself and/or another computing device in communication with the biometric monitoring device (e.g. a server). In an example embodiment, the biometric monitoring device may vibrate when a biometric goal is met.

Some embodiments of biometric monitoring devices of the present disclosure may be equipped with wireless and/or wired communication circuitry to display data on a secondary device in real time. For example, such biometric monitoring devices may be able to communicate with a mobile phone via Bluetooth Low Energy in order to give real-time feedback of heart rate, heart rate variability, and/or stress to the user. Such biometric monitoring devices may coach or grant "points" for the user to breathe in specific ways that alleviate stress (e.g. by taking slow, deep breaths). Stress may be quantified or evaluated through heart rate, heart rate variability, skin temperature, changes in motion-activity data and/or galvanic skin response.

Some embodiments of biometric monitoring devices may receive input from the user through one or more local or remote input methods. One such embodiment of local user input may use a sensor or set of sensors to translate a user's movement into a command to the device. Such motions could include but may not be limited to tapping, rolling the wrist, flexing one or more muscles, and swinging one's arm. Another user input method may be through the use of a button such as, but not limited to, capacitive touch buttons, capacitive screen buttons, and mechanical buttons. In one embodiment, the user interface buttons may be made of metal. In embodiments where the screen uses capacitive touch detection, it may always be sampling and ready to respond to any gesture or input without an intervening event such as pushing a physical button. Such biometric monitoring devices may also take input through the use of audio commands. All of these input methods may be integrated into biometric monitoring devices locally or integrated into a remote device that can communicate with such biometric monitoring devices, either through a wired or wireless connection. In addition, the user may also be able to manipulate the biometric monitoring device through a remote device. In one embodiment, this remote device may have Internet connectivity.

Alarms

In some embodiments, the biometric monitoring device of the present disclosure may act as a wrist-mounted vibrating alarm to silently wake the user from sleep. Such biometric monitoring devices may track the user's sleep quality, waking periods, sleep latency, sleep efficiency, sleep stages (e.g., deep sleep vs REM), and/or other sleep-related metrics through one or a combination of heart rate, heart rate variability, galvanic skin response, motion sensing (e.g., accelerometer, gyroscope, magnetometer), and skin temperature. The user may specify a desired alarm time or window of time (e.g., set alarm to go off between 7 am and 8 am). Such embodiments may use one or more of the sleep metrics to determine an optimal time within the alarm window to wake the user. In one embodiment, when the vibrating alarm is active, the user may cause it to hibernate or turn off by slapping or tapping the device (which is detected, for example, via motion sensor(s), a pressure/force sensor, and/or capacitive touch sensor in the device). In one embodiment, the device may attempt to arouse the user at an optimum point in the sleep cycle by starting a small vibration at a specific user sleep stage or time prior to the alarm setting. It may progressively increase the intensity or noticeability of the vibration as the user progresses toward wakefulness or toward the alarm setting. (See, for example, FIG. **8**).

FIG. **8** illustrates functionality of an example portable biometric monitoring device smart alarm feature. The biometric monitoring device may be able to detect or may be in communication with a device that can detect the sleep stage or state of a user (e.g., light or deep sleep). The user may set a window of time which they would like to be awoken (e.g., 6:15 am to 6:45 am). The smart alarm may be triggered by the user going into a light sleep state during the alarm window.

The biometric monitoring device may be configured to allow the user to select or create an alarm vibration pattern of their choice. The user may have the ability to "snooze" or postpone an alarm event. In one embodiment, the user may be able to set the amount of delay for the "snooze" feature—the delay being the amount of time before the alarm will go off again. They may also be able to set how many times the snooze feature may be activated per alarm cycle. For

example, a user may choose a snooze delay of 5 minutes and a maximum sequential snooze number to be 3. Therefore, they can press snooze up to 3 times to delay the alarm by 5 minutes each time they press snooze to delay the alarm. In such embodiments, the snooze function will not turn off the alarm if the user attempts to press snooze a fourth time.

Some biometric monitoring devices may have information about the user's calendar and/or schedule. The user's calendar information may be entered directly into the biometric monitoring device or it may be downloaded from a different device (e.g. a smartphone). This information may be used to automatically set alarms or alarm characteristics. For example, if a user has a meeting at 9 am in the morning, the biometric monitoring device may automatically wake the user up at 7:30 am to allow the user enough time to prepare for and/or get to the meeting. The biometric monitoring device may determine the amount of time required for the user to prepare for the meeting based on the user's current location, the location of the meeting, and the amount of time it would take to get the location of the meeting from the user's current location. Alternatively, historical data about how long the user takes to get to the meeting location and/or prepare to leave for the meeting (e.g. how long it takes to wake up, take a shower, have breakfast, etc. in the morning) may be used to determine at what time to wake the user. A similar functionality may be used for calendar events other than meetings such as eating times, sleeping times, napping times, and exercise times.

In some embodiments, the biometric monitoring device may use information on when the user went to sleep to determine when an alarm should go off to wake the user. This information may supplement calendar information described herein. The user may have a goal of approximately how many hours of sleep they would like to get each night or week. The biometric monitoring device may set the morning alarm at the appropriate time for the user to meet these sleep goals. In addition to amount of time that the user would like to sleep each night, other sleep goals that the user may set may include, but are not limited to, the amount of deep sleep, REM sleep, and light sleep that the user experiences while sleeping, all of which may be used by the biometric monitoring device to determine when to set an alarm in the morning. Additionally, the user may be alerted at night when they should go to bed to meet their sleep goals. Additionally, the user may be alerted during the day when they should take a nap to meet their sleep goals. The time at which to alert a user that they should take a nap may be determined by factors that optimize the user's sleep quality during the nap, subsequent naps, or night-time sleep. For example, the user is likely to have a hard time falling asleep at night if they took a nap in the early evening. The user may also be advised to eat certain foods or drinks or avoid certain foods or drinks to optimize their sleep quality. For example, a user may be discouraged from drinking alcohol close to their bed time as it is likely to decrease their sleep quality. The user may also be advised to perform certain activities or avoid certain activities to optimize their sleep quality. For example, a user may be encouraged to exercise in the early afternoon to improve their sleep quality. A user may be discouraged from exercising or watching TV close to their bedtime to improve their sleep quality.

User Interface with a Secondary Device

In some embodiments, the biometric monitoring device may transmit and receive data and/or commands to and/or from a secondary electronic device. The secondary electronic device may be in direct or indirect communication with the biometric monitoring device. Direct communication refers herein to the transmission of data between a first device and a secondary device without any intermediary devices. For example, two devices may communicate to one another over a wireless connection (e.g. Bluetooth) or a wired connection (e.g. USB). Indirect communication refers to the transmission of data between a first device and a secondary device with the aid of one or multiple intermediary third devices which relay the data. Third devices may include, but are not limited to, a wireless repeater (e.g. WiFi repeater), a computing device such as a smartphone, laptop, desktop or tablet computer, a cell phone tower, a computer server, and other networking electronics. For example, a biometric device may send data to a smartphone which forwards the data through a cellular network data connection to a server which is connected through the internet to the cellular network.

In some embodiments, the secondary device that acts as a user interface to the biometric monitoring device may consist of a smartphone. An app on the smart phone may facilitate and/or enable the smartphone to act as a user interface to the biometric monitoring device. The biometric monitoring device may send biometric and other data to the smartphone in real-time or with some delay. The smartphone may send a command or commands to the biometric monitoring device, for example, to instruct it to send biometric and other data to the smartphone in real-time or with some delay. For example, if the user enters a mode in the app for tracking a run, the smartphone may send a command to the biometric device to instruct it to send data in real-time. Therefore, the user can track their run on their app as they go along without any delay.

Such a smartphone may have one or multiple apps to enable the user to view data from their biometric device or devices. The app may, by default, open to a "dashboard" page when the user launches or opens the app. On this page, summaries of data totals such as the total number of steps, floors climbed miles traveled, calories burned, calories consumed and water consumed may be shown. Other pertinent information such as the last time the app received data from the biometric monitoring device, metrics regarding the previous night's sleep (e.g. when the user went to sleep, woke up, and how long they slept for), and how many calories the user can eat in the day to maintain their caloric goals (e.g. a calorie deficit goal to enable weight loss) may also be shown. The user may be able to choose which of these and other metrics are shown on the dashboard screen. The user may be able to see these and other metrics on the dashboard for previous days. They may be able to access previous days by pressing a button or icon on a touchscreen. Alternatively, gestures such as swiping to the left or right may enable the user to navigate through current and previous metrics.

The smartphone app may also have another page which provides a summary of the user's activities. Activities may include, but are not limited to, walking, running, biking, cooking, sitting, working, swimming, working out, weightlifting, commuting, and yoga. Metrics pertinent to these activities may be presented on this page. For example, a bar graph may show how the number of steps the user took for different portions of the day (e.g. how many steps every 5 minutes or 1 hour). In another example, the amount of time the user spent performing a certain activity and how many calories were burned in this period of time may be displayed. Similar to the dashboard page, the app may provide navigational functionality to allow the user to see these and other metrics for past days. Other time periods such as an hour, minute, week, month or year may also be selected by the user to enable them to view trends and metrics of their activities over shorter or larger spans of time.

The smartphone app may also have an interface to log food that has been, or will be, eaten by the user. This interface may

have a keyword search feature to allow the user to quickly find the food that they would like to enter into their log. As an alternative to, or in addition to, searching for foods, users may have the ability to find a food to log by navigating through a menu or series of menus. For example, a user may choose the following series of categories—breakfast/cereal/healthy/oatmeal to arrive at the food which they would like to log (e.g., apple-flavored oatmeal). At any one of these menus, the user may be able to perform a keyword search. For example, the user may search for "oatmeal" after having selected the category "breakfast" to search for the keyword "oatmeal" within the category of breakfast foods. After having selected the food that they would like to log, the user may be able to modify or enter the serving size and nutritional content. After having logged at least one food, the app may display a summary of the foods that were logged in a certain time period (e.g. a day) and the nutritional content of the foods (individual and total calorie content, vitamin content, sugar content, etc.).

The smartphone app may also have a page that displays metrics regarding the user's body such as the user's weight, body fat percentage, BMI, and waist size. It may display a graph or graphs showing the trend of one or multiple of these metrics over a certain period of time (e.g., two weeks). The user may be able to choose the value of this period of time and view previous time periods (e.g., last month).

The smartphone app may also have a page which allows the user to enter how much water the user has consumed. Each time the user drinks some water, they may enter that amount in the unit of their choice (e.g., ozs., cups, etc.). The app may display the total of all of the water the user has logged within a certain time period (e.g., a day). The app may allow the user to see previously-logged water entries and daily totals for previous days as well as the current day.

The smartphone app may also have a page that displays online friends of the user. This "friends" page may enable the user to add or request new friends (e.g., by searching for their name or by their email address). This page may also display a leaderboard of the user and his or her friends. The user and his or her friends may be ranked based on one or more metrics. For example, the user and his or her friends may be ranked using the total of the past seven days' step counts.

The smartphone app may also have a page that shows metrics regarding the user's sleep for the previous night and/or previous nights. This page may also enable the user to log when they slept in the past by specifying when they went to bed and when they woke. The user may also have the ability to enter a subjective metric about their sleep (e.g., bad night's rest, good night's rest, excellent night's rest, etc.). The user may be able to view these metrics for days or time periods (e.g., two weeks) in the past. For example, the sleep page may default to showing a bar graph of the amount of time the user slept each night in the last two weeks. The user may be able to also view a bar graph of the amount of time the user slept each night in the last month.

The user may also be able to access the full capabilities of the smartphone app described herein (e.g., the ability to enter food logs, view dashboard, etc.) through an alternative or additional interface. In one embodiment, this alternative interface may consist of a webpage that is hosted by a server in indirect communication with the biometric monitoring device. The webpage may be accessed through any internet connected device using a program such as a web browser.

Wireless Connectivity and Data Transmission

Some embodiments of biometric monitoring devices of the present disclosure may include a mechanism of wireless communication to transmit and receive information from the Internet and/or other devices. The wireless communication

may consist of one or more interfaces such as Bluetooth, ANT, WLAN, power-line networking, and cell phone networks. These are provided as examples and should not be understood to exclude other existing wireless communication methods or protocols, or wireless communications techniques or protocols that are yet to be invented.

The wireless connection may be bi-directional. The biometric monitoring device may transmit, communicate and/or push its data to other devices, e.g., smart phones, computers, etc., and/or the Internet, e.g., web servers and the like. The biometric monitoring device may also receive, request and/or pull data from other devices and/or the Internet.

The biometric monitoring device may act as a relay to provide communication for other devices to each other or to the Internet. For example, the biometric monitoring device may connect to the Internet via WLAN but also be equipped with an ANT radio. An ANT device may communicate with the biometric monitoring device to transmit its data to the Internet through the biometric monitoring device's WLAN (and vice versa). As another example, the biometric monitoring device may be equipped with Bluetooth. If a Bluetooth-enabled smart phone comes within range of the biometric monitoring device, the biometric monitoring device may transmit data to, or receive data from, the Internet through the smart phone's cell phone network. Data from another device may also be transmitted to the biometric monitoring device and stored (or vice versa) or transmitted at a later time.

Embodiments of biometric monitoring devices of the present disclosure may also include functionality for streaming or transmitting web content for display on the biometric monitoring device. The following are typical examples of such content:

1. Historical graphs of heart rate and/or other data measured by the device but stored remotely
2. Historical graphs of user activity and/or foods consumed and/or sleep data that are measured by other devices and/or stored remotely (e.g., such as at a website like fitbit.com)
3. Historical graphs of other user-tracked data that are stored remotely. Examples include heart rate, blood pressure, arterial stiffness, blood glucose levels, cholesterol, duration of TV watching, duration of video game play, mood, etc.
4. Coaching and/or dieting data based on one or more of the user's heart rate, current weight, weight goals, food intake, activity, sleep, and other data.
5. User progress toward heart rate, weight, activity, sleep, and/or other goals.
6. Summary statistics, graphics, badges, and/or metrics (e.g., "grades") to describe the aforementioned data
7. Comparisons between the aforementioned data for the user and similar data for his/her "friends" with similar devices and/or tracking methods
8. Social content such as Twitter feeds, instant messaging, and/or Facebook updates
9. Other online content such as newspaper articles, horoscopes, weather reports, RSS feeds, comics, crossword puzzles, classified advertisements, stock reports, and websites
10. Email messages and calendar schedules

Content may be delivered to the biometric monitoring device according to different contexts. For instance, in the morning, news and weather reports may be displayed along with the user's sleep data from the previous night. In the evening, a daily summary of the day's activities may be displayed.

Various embodiments of biometric monitoring devices as disclosed herein may also include NFC, RFID, or other short-range wireless communication circuitry that may be used to initiate functionality in other devices. For instance, a biometric monitoring device may be equipped with an NFC antenna so that when a user puts it into close proximity with a mobile phone, an app is launched automatically on the mobile phone.

These examples are provided for illustration and are not intended to limit the scope of data that may be transmitted, received, or displayed by the device, nor any intermediate processing that may occur during such transfer and display. In view of this disclosure/application, many other examples of data that may be streamed to or via a biometric monitoring device may be envisioned by one reasonably skilled in the art.

Charging and Data Transmission

Some embodiments of biometric monitoring devices may use a wired connection to charge an internal rechargeable battery and/or transfer data to a host device such as a laptop or mobile phone. In one embodiment, similar to one discussed earlier in this disclosure, the biometric monitoring device may use magnets to help the user align the biometric monitoring device to a dock or cable. The magnetic field of magnets in the dock or cable and the magnets in the device itself may be strategically oriented so as to force the biometric monitoring device to self-align with the dock or cable (or, more specifically, a connector on the cable) and so as to provide a force that holds the biometric monitoring device in the dock or to the cable. The magnets may also be used as conductive contacts for charging or data transmission purposes. In another embodiment, a permanent magnet may only be used in the dock or cable side and not in the biometric monitoring device itself. This may improve the performance of the biometric monitoring device where the biometric monitoring device employs a magnetometer. If there is a magnet in the biometric monitoring device, the strong field of a nearby permanent magnet may make it significantly more difficult for the magnetometer to accurately measure the earth's magnetic field. In such embodiments, the biometric monitoring device may utilize a ferrous material in place of a magnet, and the magnets on the dock or cable side may attach to the ferrous material.

In another embodiment, the biometric monitoring device may contain one or more electromagnets in the biometric monitoring device body. The charger or dock for charging and data transmission may also contain an electromagnet and/or a permanent magnet. The biometric monitoring device could only turn on its electromagnet when it is close to the charger or dock. The biometric monitoring device may detect proximity to the dock or charger by looking for the magnetic field signature of a permanent magnet in the charger or dock using a magnetometer. Alternatively, the biometric monitoring device may detect proximity to the charger by measuring the Received Signal Strength Indication (RSSI) of a wireless signal from the charger or dock, or, in some embodiments, by recognizing an NFC or RFID tag associated with the charger or dock. The electromagnet could be reversed, creating a force that repels the device from the charging cable or dock either when the device doesn't need to be charged, synced, or when it has completed syncing or charging. In some embodiments, the charger or dock may include the electromagnet and may be configured (e.g., a processor in the charger or dock may be configured via program instructions) to turn the electromagnet on when a biometric monitoring device is connected for charging (the electromagnet may normally be left on such that a biometric monitoring device that is placed on the charger is drawn against the charger by the electromagnet, or the electromagnet may be left off until the charger determines that a biometric monitoring device has been placed on the charger, e.g., through completion of a charging circuit, recognition of an NFC tag in the biometric monitoring device, etc., and then turned on to draw the biometric monitoring device against the charger. Upon completion of charging (or of data transfer, if the charger is actually a data transfer cradle or a combined charger/data transfer cradle), the electromagnet may be turned off (either temporarily or until the biometric monitoring device is again detected as being placed on the charger) and the biometric monitoring device may stop being drawn against the charger. In such embodiments, it may be desirable to orient the interface between the biometric monitoring device and the charger such that, in the absence of a magnetic force generated by the electromagnet, the biometric monitoring device would fall off of the charger or otherwise shift into a visibly different position from the charging position (to visually indicate to a user that charging or data transfer is complete).

Sensor Use in Data Transfer

In some implementations, biometric monitoring devices may include a communications interface that may switch between two or more protocols that have different data transmission rates and different power consumption rates. Such switching may be driven by data obtained from various sensors of the biometric monitoring device. For example, if Bluetooth is used, the communications interface may switch between using Bluetooth base rate/enhanced data rate (BR/EDR) and Bluetooth low energy (BLE) protocols responsive to determinations made based on data from the sensors of the biometric monitoring device. For example, the lower-power, slower BLE protocol may be used when sensor data from accelerometers in a biometric monitoring device indicates that the wearer is asleep or otherwise sedentary. By contrast, the higher-power, faster BR/EDR protocol may be used when sensor data from the accelerometers in a biometric monitoring device indicates that the wearer is walking around. Such adaptive data transmission techniques and functionality are discussed further in U.S. Provisional Patent Application No. 61/948,468, filed Mar. 5, 2014, which was previously incorporated herein by reference in the "Cross-Reference to Related Applications" section and which is again hereby incorporated by reference with respect to content directed at adaptive data transfer rates in biometric monitoring devices.

Such communication interfaces may also serve as a form of sensor for a biometric monitoring device. For example, a wireless communications interface may allow a biometric monitoring device to determine the number and type of devices that are within range of the wireless communications interface. Such data may be used to determine if the biometric monitoring device is in a particular context, e.g., indoors, in a car, etc., and to change its behavior in various ways in response to such a determination. For example, as discussed in U.S. Provisional Patent Application No. 61/948,468 (incorporated by reference above), such contexts may be used to drive the selection of a particular wireless communications protocol to use for wireless communications.

Configurable App Functionality

In some embodiments, biometric monitoring devices of the present disclosure may include a watch-like form factor and/or a bracelet, armlet, or anklet form factor and may be programmed with "apps" that provide specific functionality and/or display specific information. Apps may be launched or closed by a variety of mechanisms including, but not limited to, pressing a button, using a capacitive touch sensor, performing a gesture that is detected by an accelerometer, moving to a specific location or area detected by a GPS or motion sensor, compressing the biometric monitoring device body

(thereby creating a pressure signal inside the device that may be detected by an altimeter inside the biometric monitoring device), or placing the biometric monitoring device close to an NFC tag that is associated with an app or set of apps. Apps may also be automatically triggered to launch or close by certain environmental or physiological conditions including, but not limited to, detection of a high heart rate, detection of water using a wet sensor (to launch a swimming application, for example), a certain time of day (to launch a sleep tracking application at night, for example), a change in pressure and motion characteristic of a plane taking off or landing to launch and close an "airplane" mode app. Apps may also be launched or closed by meeting multiple conditions simultaneously. For example, if an accelerometer detects that a user is running and the user presses a button, the biometric monitoring device may launch a pedometer application, an altimeter data collection application, and/or display. In another case where the accelerometer detects swimming and the user presses the same button, it may launch a swimming lap-counting application.

In some embodiments, the biometric monitoring device may have a swim-tracking mode that may be launched by starting a swimming app. In this mode, the biometric monitoring device's motion sensors and/or magnetometer may be used to detect swim strokes, classify swim stroke types, detect swimming laps, and other related metrics such as stroke efficiency, lap time, speed, distance, and calorie burn. Directional changes indicated by the magnetometer may be used to detect a diversity of lap turn methods. In a preferred embodiment, data from a motion sensor and/or pressure sensor may be used to detect strokes.

In another embodiment, a bicycling app may be launched by moving the biometric monitoring device within proximity of an NFC or RFID tag that is located on the bicycle, on a mount on the bicycle, or in a location associated with a bicycle including, but not limited to, a bike rack or bike storage facility. (See, for example, FIG. **10**). The app launched may use a different algorithm than is normally used to determine metrics including, but not limited to, calories burned, distance traveled, and elevation gained. The app may also be launched when a wireless bike sensor is detected including, but not limited to, a wheel sensor, GPS, cadence sensor, or power meter. The biometric monitoring device may then display and/or record data from the wireless bike sensor or bike sensors.

Additional apps include, but are not limited to, a programmable or customizable watch face, stop watch, music player controller (e.g., mp3 player remote control), text message and/or email display or notifier, navigational compass, bicycle computer display (when communicating with a separate or integrated GPS device, wheel sensor, or power meter), weight-lifting tracker, sit-up reps tracker, pull up reps tracker, resistance training form/workout tracker, golf swing analyzer, tennis (or other racquet sport) swing/serve analyzer, tennis game swing detector, baseball swing analyzer, ball throw analyzer (e.g., football, baseball), organized sports activity intensity tracker (e.g., football, baseball, basketball, volleyball, soccer), disk throw analyzer, food bite detector, typing analyzer, tilt sensor, sleep quality tracker, alarm clock, stress meter, stress/relaxation biofeedback game (e.g., potentially in combination with a mobile phone that provides auditory and/or visual cues to train user breathing in relaxation exercises), teeth brushing tracker, eating rate tracker (e.g., to count or track the rate and duration by which a utensil is brought to the mouth for food intake), intoxication or suitability to drive a motor vehicle indicator (e.g., through heart rate, heart rate variability, galvanic skin response, gait analysis, puzzle solving, and the like), allergy tracker (e.g., using galvanic skin response, heart rate, skin temperature, pollen sensing and the like (possibly in combination with external seasonal allergen tracking from, for instance, the internet and possibly determining the user's response to particular forms of allergen, e.g., tree pollen, and alerting the user to the presence of such allergens, e.g., from seasonal information, pollen tracking databases, or local environmental sensors in the biometric monitoring device or employed by the user), fever tracker (e.g., measuring the risk, onset, or progress of a fever, cold, or other illness, possibly in combination with seasonal data, disease databases, user location, and/or user provided feedback to assess the spread of a particular disease (e.g., flu) in relation to a user, and possibly prescribing or suggesting the abstinence of work or activity in response), electronic games, caffeine affect tracker (e.g., monitoring the physiologic response such as heart rate, heart rate variability, galvanic skin response, skin temperature, blood pressure, stress, sleep, and/or activity in either short term or long term response to the intake or abstinence of coffee, tea, energy drinks and/or other caffeinated beverages), drug affect tracker (e.g., similar to the previously mentioned caffeine tracker but in relation to other interventions, whether they be medical or lifestyle drugs such as alcohol, tobacco, etc.), endurance sport coach (e.g., recommending or prescribing the intensity, duration, or profile of a running/bicycling/swimming workout, or suggesting the abstinence or delay of a workout, in accordance with a user specified goal such as a marathon, triathlon, or custom goal utilizing data from, for instance, historical exercise activity (e.g., distance run, pace), heart rate, heart rate variability, health/sickness/stress/fever state), weight and/or body composition, blood pressure, blood glucose, food intake or caloric balance tracker (e.g., notifying the user how many calories he may consume to maintain or achieve a weight), pedometer, and nail biting detector. In some cases, the apps may rely solely on the processing power and sensors of the present disclosure. In other cases, the apps may fuse or merely display information from an external device or set of external devices including, but not limited to, a heart rate strap, GPS distance tracker, body composition scale, blood pressure monitor, blood glucose monitor, watch, smart watch, mobile communication device such as a smart phone or tablet, or server.

In one embodiment, the biometric monitoring device may control a music player on a secondary device. Aspects of the music player that may be controlled include, but are not limited to, the volume, selection of tracks and/or playlists, skipping forward or backward, fast forwarding or rewinding of tracks, the tempo of the track, and the music player equalizer. Control of the music player may be via user input or automatic based on physiological, environmental, or contextual data. For example, a user may be able to select and play a track on their smart phone by selecting the track through a user interface on the biometric monitoring device. In another example, the biometric monitoring device may automatically choose an appropriate track based on the activity level of the user (the activity level being calculated from biometric monitoring device sensor data). This may be used to help motivate a user to maintain a certain activity level. For example, if a user goes on a run and wants to keep their heart rate in a certain range, the biometric monitoring device may play an upbeat or higher tempo track if their heart rate is below the range which they are aiming for.

Automated Functions Triggered by User's Activity

Sleep Stage Triggered Functionality

Sleep stages can be monitored through various biometric signals and methods disclosed herein, such as heart rate, heart

rate variability, body temperature, body motions, ambient light intensity, ambient noise level, etc. Such biometrics may be measured using optical sensors, motion sensors (accelerometers, gyroscopic sensors, etc.), microphones, and thermometers, for example, as well as other sensors discussed herein.

The biometric monitoring device may have a communication module as well, including, but not limited to, Wi-Fi (802.xx), Bluetooth (Classic, low power), or NFC. Once the sleep stages are estimated, the sleep stages may be transmitted to a cloud-based system, home server, or main control unit that is connected to communication-enabled appliances (with Wi-Fi, Bluetooth, or NFC) wirelessly. Alternatively, the biometric monitoring device may communicate directly with the communication-enabled appliances. Such communication-enabled appliances may include, for example, kitchen appliances such as microwaves, ovens, coffee grinders/makers, toasters, etc.

Once the sleep stages indicate that it is close the time for the user to wake up, the biometric monitoring device may send out a trigger to the appliances that the user has indicated should be operated automatically. For example, the coffee grinder and maker may be caused to start making coffee, and the toaster may be caused to start warming up bread. The microwave oven may be caused to start cooking oatmeal or eggs as well, and electric kettle to start boiling water. So long as the ingredients are appropriately prepared, this automated signal may trigger breakfast-cooking.

Alertness Detection

Alertness, e.g., a low alertness may correlate with a person being drowsy, may also be detected from the biometrics listed above, and may be used to trigger an appliance such as a coffee maker to start brewing coffee automatically.

Hydration

The portable biometric monitoring device in combination with an activity level tracker may submit the user's activity level to a cloud-based system, home server, main control unit, or appliances directly. This may trigger some actions of the appliances, especially related to hydration, such as starting the ice cube maker of a refrigerator, or lowering operating temperature of a water purifier.

Power Saving

Many appliances typically operate in a low-power idle state that consumes power. Using aggregated information of the user's biometric signals, communication-enabled appliances may be caused to go into a super-low power mode. For example, a water dispenser at home may shut itself down into a super-low-power mode when the user is asleep or out for work, and may start cooling/heating water once the user's activity at home is expected.

Restaurant Recommendation System Based on Location and Activity

Aggregation of real-time biometric signals and location information may be used to create an educated-guess on one or multiple users' needs for a given time, e.g., ionized drink. Combining this guessed need with historical user data on the user's activity levels, activity types, activity time, and activity durations, as well as food intake data logged by the users, an app on a smart phone and/or smart watch may recommend a restaurant that would meet the user's life-style and current need.

For example, a user who just finished a six mile circuit may launch this app. The app may know that this person maintained a high activity level for the past hour, and thus determine that the person may be dehydrated. From the historical user data, the app may also know, for example, that the user's diet is heavy on vegetables but low in sugar. With an optimization algorithm that considers the user's current location, price ranges, and other factors mentioned above, the app may recommend a restaurant that offers smoothies, for example.

Swim Tracking

In some embodiments of a biometric tracking device, the biometric tracking may include a swimming algorithm that may utilize data from one or more motion sensors, altitude sensors (e.g., such as a barometric pressure sensor), orientation sensors (e.g., magnetometer), location service sensor (e.g., GPS, wireless triangulation), and/or temperature sensors. The sensors may be embedded in a single device mounted to, for instance, the wrist. In other embodiments, extra sensor devices may be attached to the swimmer's forehead, back of the head, goggles, back, hip, shoulder, thighs, legs, and/or feet.

Three potential functional components of swimming exercise analysis are as follows:

Stroke count detection—provides stroke counts per lap, where a lap is defined to be a one-way traverse from one end of the pool to the opposite end.

Stroke type classification—describes the swimming stroke type of the user (e.g., crawl stroke, breast stroke, back stroke, butterfly stroke, side stroke, kicking without strokes, body streamline, etc.) and can be any or a combination of:

a. Classification of each stroke that a user takes
b. Classification of the predominant stroke type used per complete lap.
c. Classification of stroke type used per fractional lap (e.g. half a lap of freestyle, half a lap of breast stroke)

Lap count—counts the laps traversed by the user. One method of determining a lap is by detecting when the user turns in a pool.

Turning is defined to be a 180 degree change in heading direction. As a turn is detected, start and end of a lap may be inferred. Taking a break (no motion for a certain period of time) at a point in the pool (typically at one end or the other) before starting to swim again is also considered a turn as long as the following heading direction is opposite the heading prior to the break.

In some embodiments, these functional components may be combined in a multitude of ways.

Algorithm Structure

The three functional components of the swimming exercise analysis may be performed sequentially, in parallel, or in hybrid order (a combination of some sequential blocks and some parallel blocks).

Sequential Approach (See FIG. **15**A)

In one embodiment, raw and/or pre-processed sensor signals may first be analyzed by a stroke detector algorithm. The stroke detector algorithm may use temporal peaks (local maxima and/or local minima) in a motion sensor (e.g., accelerometer, gyroscope) as an indication that a stroke has been taken. Then one or more heuristic rules may also be applied to remove peaks that do not represent strokes. For example, the magnitudes of the peaks, temporal distance of two adjacent peaks, peak-to-peak amplitude, and/or morphological characteristics of the peaks (e.g., sharpness) may indicate that certain peaks do not represent strokes. When sensors provide more than one dimensional data, e.g., such as 3-axis accelerometers, or 3 axis motion sensors+altimeter (totaling 4-axis data), timings and relevant sizes of peaks in all axes may be taken into account to determine whether or not the peaks in one or more of the axes are generated by a stroke or not.

If a single peak representing a stroke or group of peaks from multiple data axes representing strokes are observed, features may be extracted from a segment of data that are obtained from the time between when the previous peak is

detected and when the current peak is detected. Features include, but are not limited to, maximum and minimum values, number of ripples in the segment, powers measured in various metrics, e.g., L1 power and L2 power, standard deviation, mean, etc. The extracted features may then be put through a machine learning system where the system coefficients are computed off-line (supervised learning) or are adapted as the user uses the biometric monitoring device (unsupervised learning). The machine learning system may then return a stroke classification for each detected stroke.

The turn-detector algorithm may search for sudden changes in motion by calculating derivatives, moving average, and/or using high-pass filtering on the signals of the sensors (the sensors including, but not limited to, those listed in this disclosure). Principal Component Analysis (PCA) can also and/or alternatively be performed on the signal(s). If one principle component is different from the sub-sequential one, then it may be determined that a turn occurred. Whole or partial coefficients of a transform, such as the Fast Fourier Transform (FFT) may be used as features as well. Parametric models such as Autoregressive (AR) models may also be used. Time-varying model parameters may then be estimated using Linear Prediction Analysis (LPA), Least Mean Squares filtering (LMS), Recursive Least Squares filtering (RLS), and/or Kalman filtering. Estimated model parameters are then compared to determine if there is an abrupt change in their values.

In one embodiment, the skill level and/or swimming styles (e.g., speed) of the swimmer may be inferred from sensor data, and then used in turn detection. For example, advanced swimmers typically have more powerful strokes (i.e., large accelerometer peak magnitudes) and take fewer strokes to complete a lap. Therefore, metrics that estimate the swimmer's skill level or characteristics may be used in a turn detection algorithm. These metrics may include, but are not limited to averaged motion signals, or integrated motion signals in particular arm movements, estimated heading speed, and detected patterns of an advanced swimmer in motion signals. The swimmer's skill level or other characteristics may also be determined through user input. For example, the user may input that they are an advanced, intermediate, or beginner swimmer.

One or many (combined) features from these analyses may be used to detect if a given data sample, and/or neighboring data samples, have characteristics of a turn. To obtain the optimal combination of the features and decision boundary, one can utilize machine learning techniques such as logistic regression, decision tree, neural nets, etc.

In some embodiments, if a turn is detected, the swimming data accrued since the previous turn may be summarized, such as the number of strokes, stroke type for each stroke and for the lap, split time, etc. If no turn is detected, the stroke counter and type may be updated. Unless the user quits swimming, the algorithm may go back to stroke count detection.

Parallel Approach (See FIG. **15**B)

In the parallel approach, some or all of the three functional components may be executed in parallel. For example, stroke-type detection and turn detection may be performed jointly, while stroke count detection is run independently.

In such embodiments, two functional components, stroke-type and turn detection, may be implemented in a single algorithm that simultaneously detects stroke-types and turns. For example, a classifier of swimming stroke types, e.g., movement analysis that detects free style strokes, breast stroke strokes, back strokes, butterfly strokes, and of turn types (e.g. tumble turn, flip turn, two hand touch) may return a detected type of stroke or a type of detected turn. During the detection, temporal as well as spectral features may be extracted. A moving window may first be applied to multiple axes of data. Statistics of this windowed segment may then be computed, namely, maximum and minimum value, number of ripples in the segment, powers measured in various metrics (e.g., L1 power and L2 power, standard deviation, mean). Independent component analysis (ICA) and/or principal component analysis (PCA) can be applied as well to find any hidden signals that better represent turn-type and stroke-type characteristics. Temporal features may then be computed from this (potentially improved) signal representation. For temporal features, various nonparametric filtering schemes, low-pass filtering, band-pass filtering, high-pass filtering, may be applied to enhance desired signal characteristics.

Spectral analysis such as FFT, wavelet transform, Hilbert transform, etc., may be applied to this windowed segment as well. Whole or partial transform coefficients may be chosen as features. Parametric models such as AR, moving average (MA), or ARMA (autoregressive and moving average) models may be used, and the parameters of such a model may be found via autocorrelation and/or partial autocorrelation, or LPA, LMS, RLS, or Kalman filter. The entire or part of estimated coefficients may be used as features.

Different lengths of moving average windows may be run in parallel, and provide features listed above, and the whole or part of the features may be utilized as features as well.

Machine-learned coefficients (supervised learning) may then be applied to these extracted features. One or more machine learning techniques, namely multiple layers of binomial linear discriminant analysis (e.g., logistic regression), multinomial logistic regression, neural net, decision tree/forest, or support vector machine, can be trained, and then used.

As the window of interest moves, the features may be extracted and these newly-extracted features will return either a stroke type or detected turn via a machine learning system.

The stroke detector algorithm may run in parallel independent of stroke type and turn detection. Temporal peaks of raw or pre-filtered sensor signals may be detected and chosen by heuristic rules.

At the summarizing stage (the stage where metrics regarding the swim may be determined, displayed, and/or stored) of the algorithm, post-processing may be applied to the sequence of stroke type and turn detections. If a turn is confirmed with certain confidence, the swimming metric data from the previous turn may be summarized along with stroke counts detected. If no turn is confirmed, the moving average window may proceed. Until the user stops swimming, the algorithm may continue to update swimming metrics regarding the exercise of the user, including, but not limited to, a total number of turns, total number of laps, total number of strokes, average strokes per lap, number of strokes in the last lap, the change in number of strokes per lap, etc.

Hybrid Approach (See FIGS. **15**C and **15**D)

In a hybrid approach, the stroke type and stroke count detection may be run in parallel, followed by turn detection.

Stroke-type detection may return a stroke type via machine learned coefficients. A first moving window may take segments of sensor signals. Then features, either entire features or a subset of the moving window features listed in herein, may be extracted. The machine learning coefficients, trained off-line, may then be applied to the features to determine which stroke-type generated the given segments of sensor signals.

Along with stroke type detection, stroke count detection may be run simultaneously.

Once the stroke type and counts are detected, turn detection may be performed with either the entire feature or a subset of the features listed.

If a turn is detected, completion of a lap may be recorded in the swimming summary metrics of the user. A post process may be applied to detected stroke types to determine the most prominent stroke type for the completed lap. Then the algorithm may move to the stroke-type and count detection stages unless the user stops swimming. If no turn is detected, the algorithm may continue updating stroke types and counts of the current lap until a turn is detected.

Blood Glucose Level and Heart Rate

Biometric monitoring devices that continuously measure biometric signals may provide meaningful information on preconditions of, progress towards, and recoveries from diseases. Such biometric monitoring devices may have sensors and run algorithms accordingly to measure and calculate biometric signals such as heart rate, heart rate variability, steps taken, calories burned, distance traveled, weight and body fat, activity intensity, activity duration and frequency, etc. In addition to the measured biometric signals, food intake logs provided by users may be used.

In one embodiment, a biometric monitoring device may observe heart rate and its changes over time, especially before and after a food intake event or events. It is known that heart rate is affected by blood sugar level, whereas it is well known that high blood sugar level is a pre-diabetic condition. Thus, mathematical models that describe the relation between time elapsed (after food intake) and blood sugar level may be found via statistical regression, where data are collected from normal, pre-diabetic, and diabetic individuals to provide respective mathematical models. With the mathematical models, one may predict whether an individual with specific heart rate patterns is healthy, pre-diabetic, or diabetic.

Knowing that many heart failures are associated with pre-diabetic or diabetic conditions, it is possible to further inform users of biometric monitoring devices with possible heart failures, e.g., coronary heart disease, cerebrovascular disease and peripheral vascular disease etc., of such risks based on their biometric data.

Users' activity intensity, type, duration, and frequency may also be taken into account, when developing the mathematical models, as an argument that controls "probability" of the disease onset, using recommended exercise guidelines such as guidelines provided by American Heart Association (http://www.heart.org/). Many guidelines on nutrition and weight management are also available in academia and to the general public to prevent cardiovascular and diabetic disease. Such guidelines may be incorporated into the mathematical models with the user data accumulated over time, such as ingredients of the food that the users consumed, and weight and body fat trends.

If users have set their family members as their friends on a social network site, which stores and displays biometric data, the likelihood of the family members getting a disease may also be analyzed and the users informed of the results.

In addition to informing users regarding a potential development of disease, recommended life-style including exercise regime and recipes with healthier ingredients and methods of preparation may be provided to the users.

Unification of Grocery Shopping, Cooking, and Food Logging

Grocery Organizing and Recipe Recognition System

Receipts from grocery shopping may contain copious information, especially regarding an individual's eating habits. A novel system that combines information from grocery store receipts with an individual's biometric data, as collected by a biometric monitoring device, for example, is presented here. The system may collect and analyze data (information) regarding an individual, and may then recommend options that may change the individual's life-style so as to improve their health. The implementation of this system may involve cloud computing, hardware platform development for sensing and interface, and mobile/website site development.

In one embodiment, when a user checks out at a grocery store, the list of groceries (as obtained from the receipt or, for example, from an email receipt or invoice) may be transmitted automatically to a remote database (e.g., a cloud server), that may also store the user's biometric data. When the user gets home and organizes items in their refrigerator and/or pantry, an app on their smart phone/watch may recommend which items in the pantry or refrigerator to throw away based on historical data on food items (e.g., if food items are expired or likely to have gone bad). Alerts indicating when food has expired or that it should be consumed in the near future to avoid spoilage may be automatically sent to the user independently of such activity. For example, these alerts may be sent out to the user whenever a certain threshold has been met (e.g., in two days the milk will expire). The alerts may also be sent to the user through mechanisms other than through a smart phone/watch. For example, the alerts may be presented to the user through a web interface, through email, through an alert on a laptop computer, on a tablet computer, desktop computer, or any other electronic device which is in direct or indirect communication with the computer which maintains and/or analyzes the database of food

Using the updated list of food items, and based on the user's historical food consumption data, the app may recommend recipes to the user. In one embodiment, preference may be given to recipes that use the items what should be eaten first (e.g., before they expire, go bad, or become less fresh faster than other ingredients). To recommend the optimal recipe that is nutritionally balanced, correctly portioned, and tailored to the user's activity, the app may also analyze the user's activity data as well. For example, if the user lifted weights in the morning, high-protein meals may be recommended. In another example, if the user was not very active, the size of the recipe may be decreased to lower the number of calories that the final meal contains.

Note that these strategies may be applied to multiple users that either share the same food and/or meals. For example, a combined food database may be created for a household so that if one member of the house got eggs and another member of the house got milk from the grocery store that both eggs and milk would be represented in the food database. Similarly, the nutritional preferences (e.g., vegetarian, allergic to certain foods, etc.), activity, basal metabolic rate, and total calorie burn may be used to form a recommendation on what food/recipe to prepare and/or purchase.

Biometric signals including, but not limited to, heart rate and heart rate variability may provide indications of preconditions of diseases. This information may be used to recommend that the user purchase, consume, and/or prepare particular foods so as to reduce their risk of the disease(s) for which they have the pre-conditions. For example, if a user has a precondition for cardiac problems, it may be recommended that they purchase more vegetables, consume less fatty foods, and prepare food in methods which require less oil (e.g., not deep frying).

Control "Smart Appliance"

In another embodiment, various appliances may all be Wi-Fi enabled, and may communicate with servers. Since the app (which may be connected to the appliances via, for example, the cloud or the Internet) may know which food

items the refrigerator contains, the app may communicate with the refrigerator to lower or raise the temperature of the refrigerator depending on the food items. For example, if many of the food items are more sensitive to cold, such as vegetables, the refrigerator may be instructed to raise the temperature. The app may also directly communicate with the refrigerator as well via Bluetooth, BTLE, or NFC.

Food Logging

The app may also provide items to log in as the user's food based on a grocery shopping list (which may, for example, be a list maintained within the app) and food recipes that the app recommended. In case of precooked meals (e.g., frozen dinner) or produce that does not require any further processing before being eaten, the user may simply input their serving size (or in the case that the user eats the whole meal, the user may not need to enter a serving size), and then the food logging will be completed. Since the grocery list or receipt provides the exact brand and maker of certain foods, more accurate nutritional information may be logged into the user's account.

When a user logs a food item that is cooked by following a recipe suggested by the app, the app may calculate nutritional information from the ingredients and cooking procedure. This may provide more accurate estimate of calorie intake than a simple categorization of the end product/meal, since many recipes exist to prepare a particular type of food, e.g., meatballs for pasta may be made with beef, turkey, pork, etc., and may include varying degrees of carbohydrates.

Sport Metric Acquisition Using a Sensor Device

In some embodiments, a sensor may be mounted on a racket, e.g., tennis racket, to help to measure the different strokes of the player. This may be applicable to most, if not all, racket sports including, but not limited to, tennis, racquetball, squash, table tennis, badminton, lacrosse, etc., as well as sports played with a bat like baseball, softball, cricket, etc. Similar techniques may also be used to measure different aspects of golf. Such a device can be mounted on the base of the racket, on the handle or on the shock absorber typically mounted on the strings. This device may have various sensors like an accelerometer, gyroscope, magnetometer, strain sensor, and/or microphone. The data from these sensors may either be stored locally or transmitted wirelessly to a host system on a smartphone or other wireless receiver.

In some embodiments of a biometric monitoring device, a wrist mounted biometric monitoring device including an accelerometer, gyroscope, magnetometer, microphone, etc. may perform similar analysis of the user's game or motions. This biometric monitoring device may take the form of a watch or other band worn on the user's wrist. Racket- or bat-mounted sensors that measure or detect the moment of impact between the bat or racket and the ball and wirelessly transmit such data to the wrist-mounted biometric monitoring device may be used to improve accuracy of such algorithms by accurately measuring the time of impact with the ball.

Both wrist and racket-/bat-mounted devices may help measure different aspects of the user's game including, but not limited to, stroke-type (forehand, backhand, serve, slice, etc.), number of forehands, number of backhands, ball spin direction, topspin, service percentage, angular velocity of racket head, backswing, shot power, shot consistency, etc. The microphone or the strain sensor may be used in addition to the accelerometer to identify the moment at which the ball impacts the racket/bat. In cricket and baseball, such a device may measure the backswing, the angular velocity of the bat at the time of impact, the number of shots on the off-side vs. leg-side (cricket). It may also measure the number of swings and misses and the number of defensive vs. offensive strokes.

Such a device may also have a wireless transmitter to transmit such statistics in real time to a scoreboard or to individual devices held by spectators.

The wrist- or racket-mounted device may have a small number of buttons (e.g., two) that may be used by the player to indicate when a volley is won or when an unforced error occurs. This will allow the algorithm to calculate the fraction of winners and unforced errors that are forehands vs. backhands. The algorithm may also keep track of the number of aces vs. double-faults in tennis. If both players use such a system, the system may also automatically keep track of the score.

Bicycle Handlebar Based ECG

In some embodiments of biometric monitoring devices, a user's heart rate may be monitored using an electrode in contact with the left hand and an electrode in contact with the right hand (an ECG heart rate measurement). As riding a bicycle requires the user to make hand contact with either side of the handlebars, this particular activity is well suited to tracking user heart rate using ECG techniques. By embedding electrodes in the handlebars or handlebar grips or tape, the user's heart rate may be measured whenever the user is holding the handlebars. For bicycles that have grips (as opposed to using handlebar tape), electrodes may be incorporated into a special grip that may be used to replace the existing grips, e.g., the factory-installed grips, which are typically non-conductive. The left and right grips may be electrically connected to electronics that measure the ECG signal, using a wire, for example. In the case that the handlebars themselves are conductive, the handlebars may be used to electrically connect one of the grips to the electronics that measure the ECG signal. The electronics that measure the ECG signal may be incorporated into one or both of the grips. Alternatively, the electronics that measure the ECG signal may be located in a separate housing. In one embodiment, this separate housing may be mounted on the bicycle handlebar or stem. It may have functions and sensors that typical bicycle computers have (e.g., speed sensor, cadence sensor, GPS sensor). It may also have atypical sensors such as a wind speed sensor, GSR sensor(s), and accelerometer sensor (potentially also incorporated into the handlebars). This embodiment may use techniques described in this disclosure to calculate activity metrics including, but not limited to, calorie burn, and transmit these metrics to secondary and tertiary device(s) (e.g. smartphones and servers).

Electrodes for the ECG may be incorporated into parts of the bike or accessories other than into grip tape and handlebar grips such as into gloves, brake hoods, brake levers, or the handlebars themselves. These electrodes or additional electrodes may be used to measure GSR, body fat and hydration in addition to, or in alternative to, heart rate. In one example, the user's heart rate may be measured using conductive threads (used as ECG electrodes) sewn into grip tape installed on the handlebar. The grip tape electrodes may be connected to a central bike computer unit that contains electronics to measure GSR, hydration, and/or heart rate. The biometric monitoring device may display this information on a display. If the user's hydration or heart rate exceeds a certain threshold, the user may be alerted to drink more, drink less, increase intensity or decrease intensity. In the case that the bike computer measures only one or two of GSR, hydration or heart rate, algorithms may be used to estimate metrics which that cannot be measured directly. For example, if the biometric monitoring device can only measure heart rate and duration of exercise, a combination of heart rate and duration of exercise may be used to estimate hydration and alert the user when they should drink. Similarly, heart rate and exercise duration

may be used to alert the user when they should eat or drink something other than water (e.g., a sports drink).

Indirect Metric Estimation

Bicycle computers typically measure a variety of metrics including, but not limited to, speed, cadence, power, and wind speed. In the case that the portable monitoring device does not measure these metrics or is not in communication with devices which may be able to supply these metrics, these and other metrics may be inferred using the sensors that the portable biometric monitoring device does have. In one embodiment, the portable biometric monitoring device may measure heart rate. It may use this measurement to infer/estimate the amount of power that the user is outputting. Other metrics such as the user's age, height, and weight may help inform the power measurement. Additional sensor data such as GPS-measured speed, altitude gain/descent, bicycle attitude (so as the measure the incline or decline of a slope), and accelerometer signals may be used to further inform the power estimate. In one embodiment, an approximately linear relationship between heart rate and power output may be used to calculate the user's power output.

In one embodiment, a calibration phase may occur where the user takes data from the portable biometric monitoring device and a secondary device that may be used during calibration as a baseline but not be used at a later time (e.g., a power meter). This may allow a relationship between sensor data measured by the portable monitoring device and sensor data measured by the secondary device data to be determined. This relationship may then be used when the secondary device is not present to calculate estimated values of data that is explicitly provided by the secondary device but not by the biometric monitoring device.

Activity Based Automatic Scheduling

In one embodiment, the day's travel requirements (to work, from work, between meetings) may be scheduled for the user based on the information in their calendar (or emails or text messages etc.), with the aim of meeting daily activity goal(s) or long term activity goal(s). The user's historical data may be used to help plan both meeting the goal(s) and also the transit time required. This feature may be combined with friends or colleagues. The scheduling may be done such that a user may meet a friend along the way as they walk to work, or meet a colleague on the way to a meeting (the user might need to set a rendezvous point, though). If there is real-time communication between biometric monitoring devices of the user and the user's friend, the user may be directed to walk a longer route if data from the friend's biometric monitoring device indicates that their friend is running late.

In another embodiment, walking/running/fitness routes may be suggested to the user based (in whole or in part) on their proximity to the user. The data for such recommendations could also or additionally be based on GPS info from other users. If there is real-time communication, the user may be directed to a busy route or a quiet route as preferred. Knowing heart rate and basic fitness information about other users may allow the system to suggest a route to match a user's fitness level and the desired exercise/exertion level. Again this information may be used for planning/guiding a user to longer term activity/fitness goals.

Location/Context Sensing and Applications

Through one or more methods, embodiments of the biometric monitoring devices disclosed herein may have sensors that can determine or estimate the location and or context (e.g. in a bus, at home, in a car) of the biometric monitoring device. Purpose-built location sensors such as GPS, GLONASS, or other GNSS (Global Navigation Satellite System) sensors may be used. Alternatively, location may be inferred, estimated or guessed using less precise sensors. In some embodiments in which it is difficult to know the user's location, user input may aid in the determination of their location and or context. For example, if sensor data makes it difficult to determine if a user was in a car or a bus, the biometric monitoring device or a portable communication device in communication with the biometric monitoring device or a cloud server which is in communication with the biometric monitoring device may present a query to the user asking them if they took the bus today or took a car. Similar queries may occur for locations other than vehicular contexts. For example, if sensor data indicate that the user completed a vigorous workout, but there is no location data that indicates that the user went to a gym, the user may be asked if they went to the gym today.

Vehicular Transportation Detection

In some embodiments, sensors of the biometric monitoring device and/or a portable electronic device in communication with the biometric monitoring device and/or a server which communicates with the biometric monitoring device may be used to determine what type of vehicle (if any) the user is, or was, in. Note that in the embodiments below, a sensor in one or more biometric monitoring devices and/or portable electronic devices may be used to sense the relevant signal. Also note that while specific network protocols such as WiFi or Bluetooth may be used in the following descriptions, one or more alternative protocols such as RFID, NFC, or cellular telephony may also be used.

In one embodiment, the detection of a Bluetooth device associated with a vehicle may be used to infer that the user is in a vehicle. For example, a user may have a car that has a Bluetooth multimedia system. When the user gets close enough to their car for a long enough period of time, the sensor device may recognize the Bluetooth identification of the multimedia system and assume that the user is in the car. Data from other sensors may be used to corroborate the assumption that the user is in the vehicle. Examples of data or signals from other sensors that may be used to confirm that the user is in a car include a GPS speed measurement that is higher than 30 mph and accelerometer signals that are characteristic of being in a car. Information intrinsic to the Bluetooth ID may be used to determine that it is a Wi-Fi router of a vehicle or type of vehicle. For example, the Bluetooth ID of a router in a car may be "Audi In-Car Multimedia." The keyword "Audi" or "Car" may be used to guess that the router is associated with a vehicle type of "car." Alternatively, a database of Bluetooth ID's and their associated vehicles may be used.

In one embodiment, a database of Bluetooth ID's and their associated vehicles may be created or updated by the user of a biometric monitoring device or through portable communication device data. This may be done with and/or without the aid of user input. In one embodiment if a biometric monitoring device can determine whether or not it is in a vehicle, vehicle type, or specific vehicle without the use of Bluetooth ID, and it encounters a Bluetooth ID that moves with the vehicle, it may send the Bluetooth ID and information regarding the vehicle to a central database to be catalogued as a Bluetooth ID that corresponds with a vehicle. Alternatively, if a user inputs information about the vehicle they are in or were in at a previous point in time and there is a Bluetooth ID that was encountered during or close to the time that the user indicated they were in the vehicle, the Bluetooth ID and vehicle information may be sent to a central database and associated with one another.

In another embodiment, the detection of a Wi-Fi device associated with a vehicle may be used to infer that the user is

in that vehicle or type of vehicle. Some trains, buses, airplanes, cars, and other vehicles have Wi-Fi routers in them. The SSID of the router may be detected and used to infer or aid an inference that a user is in a specific vehicle or type of vehicle.

In one embodiment, a database of SSID's and their associated vehicles may be created or updated with the user of a biometric monitoring device or through portable communication device data. This may be done with and/or without the aid of user input. In one embodiment, if a biometric monitoring device can determine whether or not it is in a vehicle, vehicle type, or specific vehicle without the use of an SSID, and it encounters an SSID that moves with the vehicle, the biometric monitoring device may send the SSID and information regarding the vehicle to a central database to be catalogued as an SSID that corresponds with a vehicle. Alternatively, if a user inputs information about the vehicle they are in or were in at a previous point in time and there is an SSID that was encountered during or close to the time that the user indicated they were in the vehicle, the SSID and vehicle information may be sent to a central database and associated with one another.

In another embodiment of a biometric monitoring device, location sensors may be used to determine the track of a user. This track may then be compared to a database of routes for different modes of transit. Modes of transit may include, but are not limited to walking, running, biking, driving, taking a bus, taking a train, taking a tram, taking the subway, and/or motorcycling. If the user's track corresponds well with a route of a specific mode of transit, it may be assumed that the user used that mode of transit for the period of time that it took them to traverse the route. Note that the speed with which the route or sections of the route were completed may improve the guess of the mode of transit. For example, a bus and a car may both be able to take the same route, but the additional stopping of the bus at bus stops may allow the device to determine that the user was taking a bus rather than a car. Similarly, the discrimination between biking and driving a route may be aided by the typical difference of speed between the two. This difference in speed may also depend on the time of day. For example, some routes may be slower by car during rush hour.

In another embodiment, a biometric monitoring device may be able to detect that the user is in or near a vehicle based on measurements of the magnetic field of vehicle. In some embodiments, the magnetic field signature of a location typically associated with the vehicle (e.g., train station, subway station, bus stop, car garage) may also be used to infer that the user is currently in, will be, or has been in a vehicle. The magnetic field signature may be time invariant or time varying.

If it is determined that the user was indeed in a vehicle for a period of time, other metrics about the user may be modified to reflect such a status. In the case that the biometric monitoring device and/or portable electronic device can measure activity metrics such as steps taken, distance walked or run, altitude climbed, and/or calories burned, these metrics may be modified based on information about vehicular travel. If any steps taken or altitude climbed were incorrectly logged during the time that the user is in a vehicle, they may be removed from the log of metrics about the user. Metrics derived from the incorrectly logged steps taken or altitude climbed such as distance traveled and calories burned may also be removed from the log of metrics about the user. In the case that it can be determined in real-time or near real-time whether or not the user is in a vehicle, the sensors detecting metrics which should not be measured while in a vehicle (e.g. steps taken, stairs climbed) may be turned off or algorithms which are used to measure these metrics may be turned off to prevent incorrectly logged metrics (as well to save power). Note that metrics regarding vehicle use such as type of vehicle taken, when it was taken, which route was taken, and how long the trip took may be recorded and used later to present the user with this data and/or to correct other activity and physiological metrics about the user.

Location Sensing Using Bluetooth

Methods similar to those described above may also be used by a biometric monitoring device to determine when the user comes into proximity of static locations. In one embodiment, Bluetooth ID's from computers (e.g., tablet computers) at restaurants or stores may be used to determine the user's location. In another embodiment, semi-fixed Bluetooth ID's from portable communication devices (e.g., smartphones) may be used to determine a user's location. In the case of semi-fixed Bluetooth ID sources, multiple Bluetooth ID's may be need to reach an acceptable level of confidence of the location of the user. For example, a database of Bluetooth ID's of the coworkers of a user may be created. If the user is within range of several of these Bluetooth ID's during typical working hours, it may be assumed that the user is at work. The detection of other Bluetooth ID's may also be used to record when two users meet up. For example, it may be determined that a user went for a run with another user by analyzing pedometer data and Bluetooth ID's. Similar such concepts are discussed in further detail in U.S. Provisional Patent Application No. 61/948,468, filed Mar. 5, 2014, and previously incorporated by reference with regard to such concepts.

Uncertainty Metric for GPS Based on Location

When fusing sensor signals with GPS signal to estimate informative biometrics, such as steps, live pace, speed, or trajectory of trips, quality of the GPS signal is often very informative. However, GPS signal quality is known to be time-varying, and one of the factors that affects the signal quality is environmental surroundings.

Location information may be used to estimate GPS signal quality. A server may store a map of area types, where the area types are pre-determined by number and kind of objects that deteriorate GPS signals. The types may, for example, be: large building area, small building area, open area, side-by-water area, and forested area. These area types are then queried when GPS sensor gets turned on with its very first few location estimates, which are expected to be rough and inaccurate. With the rough GPS estimates of the location, possible types of areas may be returned, and these area types may then be taken into account in the calculation of the GPS signal quality and reliability.

For example, if a user is in or near an urban canyon (an area surround by tall buildings) such as downtown San Francisco, a low certainty may be associated with any GNSS location measurements. This certainty may be used later by algorithms that attempt to determine the user's track, speed, and/or elevation based on, at least in part, GPS data.

In one embodiment, a database of location and GPS signal quality may be created automatically using data from one or more GNSS sensors. This may be automatically performed by comparing the GNSS tracks with a map of streets and seeing when the GNSS sensors show characteristics of a user travelling along a street (e.g., having a speed of 10 mph or higher), but their track is not located on a road. The database of GPS certainty based on approximate location may also be inferred from maps showing where there are tall buildings, canyons, or dense forests.

Location Sensing Using Vehicular GNSS and/or Dead Reckoning

Many vehicles have integrated GNSS navigation systems. Users of vehicles that don't have integrated GNSS navigations systems often buy a GNSS navigation system for their car that is typically mounted non-permanently in the driver's field of view. In one embodiment, a portable biometric monitoring device may be able to communicate with the vehicle's GNSS system. In the case where the portable biometric monitoring device is also used to track location, it may receive location information from the vehicle GNSS. This may enable the biometric monitoring device to turn off its own GNSS sensor (in the case that it has one), therefore reducing its power consumption.

In addition to GNSS location detection, a vehicle may be able to transmit data about its steering wheel orientation and/or its orientation with respect to the earth's magnetic field in addition to its speed as measured using the tire size and tire rotational velocity. This information may be used to perform dead-reckoning to determine a track and/or location in the case that the vehicle does not have a GNSS system or the vehicle's GNSS system cannot get a reliable location measurement. Dead-reckoning location information may supplement GNSS sensor data from the biometric monitoring device. For example, the biometric monitoring device may reduce the frequency with which it samples GNSS data and fill in the gap between GNSS location data with locations determined through dead reckoning.

Step Counter Data Fusion with Satellite-Based Location Determination

In some implementations of a biometric monitoring device, data from various different sensors may be fused together to provide new insights as to activities of the wearer of the biometric monitoring device. For example, data from an altimeter in the biometric monitoring device may be combined with step count data obtained by performing peak detection analysis on accelerometer data from an accelerometer of the biometric monitoring device to determine when the wearer of the biometric monitoring device is, for example, climbing stairs or walking uphill (as opposed to riding an elevator or an escalator or walking across flat ground).

In another example of sensor data fusion, data from a step counter such as that discussed above may be combined with distance measurements derived from GPS data to provide a refined estimate of total distance traveled within a given window. For example, GPS-based distance or speed data may be combined with step-counter-based distance or speed (using steps taken multiplied by stride length, for example) using a Kalman filter in order to obtain a refined distance estimate that may be more accurate than either the GPS-based distance or speed measurement or the step-counter-based distance or speed measurement alone. In another implementation, a GPS-based distance measurement may be filtered using a smoothing constant that is a function of the step rate as measured by, for example, an accelerometer. Such implementations are discussed further in U.S. Provisional Patent Application No. 61/973,614, filed Apr. 1, 2014, which was previously incorporated herein by reference in the "Cross-Reference to Related Applications" section and which is again hereby incorporated by reference with respect to content directed at distance or speed estimation refinement using data from satellite-based location systems and step count sensors.

Biometric and Environmental/Exercise Performance Correlation

Some embodiments of portable monitoring devices described herein may detect a variety of data including biometric data, environmental data, and activity data. All of this data may be analyzed or presented to a user to facilitate analysis of or correlation between two or more types of data. In one embodiment, a user's heart rate may be correlated to car speed, biking speed, running speed, swimming speed or walking speed. For example, the user may be presented with a graph that plots biking speed on the X axis and heart rate on the Y axis. In another example, a user's heart rate may be correlated to music that they were listening to. The biometric monitoring device may receive data regarding what music the user was listening to through a wireless connection (e.g., Bluetooth) to a car radio. In another embodiment, the biometric monitoring device may also function as a music player itself, and therefore can record which song was played when.

Weight Lifting Aid

Without the aid of a personal trainer or partner, it may be difficult to do a weight-lifting routine properly. A portable biometric monitoring device may aid a user in completing a weight lifting routine by communicating to the user how long they should hold up each weight, how quickly they should lift it, how quickly they should lower it, and how many repetitions of each lift to perform. The biometric monitoring device may measure the user's muscle contractions using one or more EMG sensors or strain sensors. The user's muscle contractions may also be inferred by measuring vibrations of one or more body parts (for example using an accelerometer), sweat (e.g., using a GSR sensor), rotation of one or multiple body parts (e.g., using a gyroscope), and/or a temperature sensor on one or more body parts. Alternatively, a sensor may be placed on the weight lifting apparatus itself to determine when the using is lifting, with how much speed they are lifting or lowering, how long they are lifting for, and how many repetitions of lifts they have performed.

In one embodiment, if the biometric monitoring device or weight lifting apparatus detects that the user is approaching their failure limit (when the user can no longer support the weight), the weight lifting apparatus may automatically lift the weight or prevent the weight from being lowered. In another embodiment, a robot in communication with the biometric monitoring device or weight lifting apparatus may automatically lift the weight or prevent the weight from being lowered. This may allow the user to push themselves to their limit without needing a partner/spotter (to lift the weight in case of failure) and without risking injury from dropping the weight.

Glucose Level Monitoring Aid

In some embodiments, a portable biometric monitoring device may be configured to aid users who need to monitor their glucose levels (e.g., diabetics). In one embodiment, the portable biometric monitoring device may indirectly infer a user's glucose level or a metric related to the user's glucose level. Sensors other than those typically used in monitoring glucose monitoring (using continuous or discrete finger-prick types of sensors) may be used in addition to, as an alternative to, or as an aid to the typical glucose monitoring methods. For example, an biometric monitoring device may alert the user that they should check their blood glucose level based on data measured from sensors on the biometric monitoring device. If the user has performed a certain type of activity for a certain amount of time, their blood glucose level is likely to have decreased, and therefore, the biometric monitoring device may display an alert, create an auditory alert, or vibrate to alert the user that their blood glucose may be low and that they should check it using a typical glucose measurement device (e.g., a finger-prick type glucose monitor). The biometric monitoring device may allow the user to input the glucose level that is measured from the glucose meter. Alternatively,

the glucose measurement may be automatically transmitted to the biometric monitoring device and/or a third device in direct or indirect communication with the biometric monitoring device (e.g., a smart phone or server). This glucose measurement may be used to inform the algorithm used by the biometric monitoring device to determine when the next glucose level alert should be delivered to the user. The user may also be able to enter what food they ate, are eating, or are planning to eat into the biometric monitoring device or a device in direct or indirect communication with the biometric monitoring device. This information may also be used to determine when the user should be alerted to check their blood glucose level. Other metrics and sensor data described herein (e.g., heart rate data) may also be used alone or in combination to determine when the user should be alerted to check their blood glucose.

In addition to being alerted when glucose levels should be checked, a biometric monitoring device may also display an estimate of the current glucose level. In another embodiment, data from the biometric monitoring device may be used by a secondary device (e.g., a smart phone or server) to estimate the user's glucose level and/or present this data to the user (e.g., by displaying it on a smartphone, on a webpage, and/or by communicating the data through audio).

A biometric monitoring device may also be used to correlate exercise, diet, and other factors to blood glucose level. This may aid users in seeing the positive or negative effects of these factors on their blood glucose levels. The blood glucose levels with which the activity is correlated to may be measured by the user using a different device (e.g., a finger-prick monitor or continuous blood glucose monitor), by the biometric monitoring device itself, and/or by inferring the blood glucose level or a metric related to the glucose level using other sensors. In some embodiments of biometric monitoring devices, a user may wear a continuous glucose monitoring device and a biometric monitoring device. These two devices may automatically upload data regarding activities and glucose levels to a third computing device (e.g., a server). The server may then analyze the data and/or present the data to the user so that they become more aware of the relationship between their activities and glucose levels. The server may also receive input on the user's diet (e.g., the user may enter what foods they eat) and correlate the diet with glucose levels. By helping the user understand how diet, exercise, and other factors (e.g., stress) affects their blood glucose levels, biometric monitoring devices may aid users who have diabetes.

UV Exposure Detection

In one embodiment, the biometric monitoring device may have the ability to monitor an individual's exposure to UV radiation. UVA and UVB may be measured with one or multiple sensors. For example, a photodiode having a bandpass filter which passes only UVA may detect UVA exposure and a photodiode having a bandpass filter which passes only UVB may detect UVB exposure. The user's skin pigmentation may also be measured using a camera or reflectometer (light emitter and light detector which determines the efficiency with which light is reflected off the skin). Using UVA, UVB, and skin pigmentation data, the biometric monitoring device may provide a user with information regarding the amount of UV exposure they have been subjected to. The biometric monitoring device may also provide estimates or alarms regarding over exposure to UV, potential for sunburn, and potential for increasing their risk of skin cancer.

Screen Power Saving Using User Presence Sensors

The portable biometric monitoring device may have one or more a displays to present information to the user. In one embodiment sensors on the biometric monitoring device may determine the user is using the biometric monitoring device and/or wearing the biometric monitoring device to determine the state of the display. For example, a biometric monitoring device having a PPG sensor may use the PPG sensor as a proximity sensor to determine when the user is wearing the biometric monitoring device. If the user is wearing the biometric monitoring device, the state of the screen (e.g. a color LCD screen) may be changed to "on" or "standby" from its typical state of being off.

Power Conservation with Respect to Satellite-Based Location Determination Systems

In some implementations, certain systems included in a biometric monitoring device may consume relatively large amounts of power compared to other systems in the biometric monitoring device. Due to the small space constraints of many biometric monitoring devices, this may seriously affect overall battery charge life for the biometric monitoring device. For example, in some biometric monitoring devices, a satellite-based location determination system may be included. Each time the satellite-based location determination system is used to obtain a position fix using data from the GPS satellite constellation, it uses power drawn from the biometric monitoring device battery. The biometric monitoring device may be configured to alter the frequency with which the satellite-based location determination system obtains a location fix based on data from one or more sensors of the biometric monitoring device. This adaptive location fix frequency functionality may help conserve power while still allowing the satellite-based location determination system to provide location fixes at useful intervals (when appropriate).

For example, if a biometric monitoring device has an ambient light sensor, data from the ambient light sensor may be used to determine whether the lighting conditions indicate that the biometric monitoring device is likely indoors as opposed to outdoors. If indoors, the biometric monitoring device may cause the location fix frequency to be set to a level that is lower than the location fix frequency that may be used when the lighting conditions appear to indicate that the biometric monitoring device is outdoors. This has the effect of decreasing the number of location fixes that are attempted when the biometric monitoring device is indoors and thus less likely to obtain a good location fix using a satellite-based location determination system.

In another example, if motion sensors of the biometric monitoring device indicate that the wearer of the biometric monitoring device is substantially stationary, e.g., sleeping or generally not moving more than a few feet every minute, the location fix frequency of the satellite-based location determination system may be set to a lower level than if the motion sensors indicate that the wearer of the biometric monitoring device is in motion, e.g., walking or running from one location to another, e.g., moving more than a few feet.

In yet another example, the biometric monitoring device may be configured to determine if the biometric monitoring device is actually being worn by a person—if not, the biometric monitoring device may set the location fix frequency to a lower level than if the biometric monitoring device is actually being worn. Such determinations regarding whether or not the biometric monitoring device is being worn may be made, for example, when motion data collected from motion sensors of the biometric monitoring device indicate that the biometric monitoring device is substantially immobile, e.g., not even demonstrating small movements experienced by biometric monitoring devices when the wearer is sleeping or sedentary, or when data, for example, from a heart rate sensor indicates that no heart rate is detected. For optical heart rate sensors, if there is little or no change in the amount of light

detected by the light detection sensor when the light source is turned on and off, this may be indicative of the fact that the heart rate sensor is not pressed against a person's skin and that, by inference, the biometric monitoring device is not being worn. Such adaptive satellite-based location determination system fix frequency concepts are discussed in more detail in U.S. Provisional Patent Application No. 61/955,045, filed Mar. 18, 2014, which was previously incorporated herein by reference in the "Cross-Reference to Related Applications" section and which is again hereby incorporated by reference with respect to content directed at power conservation in the context of satellite-based location determination systems.

It is to be understood that biometric monitoring devices, in addition to including the features discussed below in more detail, may also include one or more features or functionalities discussed above or discussed in the various applications incorporated by reference in the above discussion. Such implementations are to be understood as being within the scope of this disclosure.

While the above discussion has focused on a variety of different systems and functionality that may be included in a biometric monitoring device, the discussion that follows below focuses on some particular embodiments (some of which may also be discussed above) in further detail.

Heart Rate Monitor with Automatic Detection of Unworn and Worn States

Some embodiments provide methods for operating a heart rate monitor of a wearable fitness monitoring device to measure one or more characteristics of a heartbeat waveform. A "heartbeat waveform" as used herein refers to a variation of any measured signal caused by or correlated with a user's heartbeat driven blood flow. In some embodiments, the measured signal relates to blood circulation caused by the heart pumping blood through the circulatory system, which causes cardiovascular driven variations in capillary volume or other parameter. In some embodiments, the heartbeat waveform is measured by photoplethysmography (PPG). In such embodiments, the heartbeat waveform reflects blood volume changes in capillaries, which correlates with a user's heartbeat and pulse (an arterial palpation caused by the heartbeat). In some embodiments, the measured signal relates to muscular activities of the heart or electrocardiographic signals. In some embodiments, the cardiac activities or signals can be measured by ECG to obtain the heartbeat waveform.

A heartbeat waveform represents information for one or more cardiac cycles, which corresponds to a complete heartbeat from its generation to the beginning of the next beat. The frequency of the cardiac cycle is described by the heart rate, which is typically expressed as beats per minute. A heartbeat waveform typically includes information about various stages of a heartbeat, e.g., amplitude, frequency, and/or shape of waveform over one or more cardiac cycles. In many embodiments, a heartbeat waveform is used to obtain a user's heart rate.

In some embodiments, optical heart rate monitors may be used in the wearable device, implementing different modes of operation by emitting pulses of light and detecting light after it interacts with the user's skin or other tissue, to thereby capture data that may be used to obtain the user's heartbeat waveform, worn state, user characteristics, etc.

In some embodiments, the current disclosure provides methods for operating a wearable fitness monitoring device having a heart rate monitor (HRM) in a low power state when the device determines that the device is not worn by a user, or is "off-wrist" when implemented in a wrist-worn device. This feature of the HRM is also referred to as an "automatic off" function. In some embodiments, the automatic off function is implemented by operating the HRM in an "unworn" (or "off-wrist") detection mode, and the automatic off function automatically turns off the heart rate monitoring operations of the HRM to conserve energy if the device determines that it is not being worn by the user. Other benefits of the automatic off function include providing more accurate heart rate estimation. For example, when an automatic off or automatic on (described below) is performed a heart rate detection algorithm may reset. In one implementation, the algorithm stops running when off-wrist is detected, and restarts when on-wrist is detected. When the heart rate monitor restarts, it resets.

In some embodiments, the current disclosure provides methods for operating a wearable fitness monitoring device having a heart rate monitor in a normal power state when the device is worn by the user, or "on-wrist" when implemented in a wrist-worn device. This feature of the HRM is also referred to as an "automatic on" function. In some embodiments, the automatic on function is implemented by operating the HRM in a "worn" (or "on-wrist") detection mode. The automatic on function automatically takes the HRM out of a low power state and turns on the heart rate monitoring operations of the HRM if the device detects motion and determines that it is worn by the user.

In some embodiments, the unworn (or off-wrist) and worn (or on-wrist) detection may be implemented by light (e.g., LED) probing, which emits light pulses and detects signals after the light pulses interact with the user's skin and tissues. In some embodiments, the unworn and worn probing may share some hardware, firmware, software, and/or parameters for light emission, light detection, and analyses of detected signals. In other embodiments, the two probing modes employ different hardware, firmware, software, and/or parameters for light emission, light detection, and analyses may be used for unworn and worn detection.

In some embodiments, the wearable fitness monitoring device goes in and out of the low power state regulated by a probe light (e.g., LED) and a motion detector, implementing automatic off and on functions. In the low power state, the heart rate monitor saves power by turning off, or scaling back operation of, its LED light source and its photodetector. In some embodiments, other light sources and light detectors (e.g., photodiodes, photomultiplier tubes, CCD, or CMOS) may be used to implement the automatic off and on functions. FIG. **17**A shows such an implementation, where in the same probe light mechanism is used to determine whether the heart rate monitor is worn ("on-wrist") or unworn ("off-wrist"). In other embodiments described below, two different probe light mechanisms may be used to determine the on-wrist state and the off-wrist state of the monitor. As one skilled in the art will recognize, although the heart rate monitors described herein are described as being worn on the wrist of the user, other types of implementation may allow the user to wear the heart rate monitor in alternative fashions, such as on the ankle or the chest of the user. In such implementations, the worn state and unworn state respectively correspond to the "on-wrist state" and "off-wrist" state of the implementations described below.

As shown in FIG. **17**A, an LED or another light source emits pulses of light that can be detected by a photodetector of the heart rate monitor of a wearable fitness monitoring device (also referred to as a wearable device). Typically when the device is worn by the user, the emitted light will interact with the skin and/or other tissue of the user, and then be detected by the photodetector of the heart rate monitor. If the device is not worn by the user, the emitted light will not be detected by the photodetector, or will be detected with a different intensity or

pattern. The difference in detected light provides data that the heart rate monitor may analyze to determine whether the device is being worn by the user on not. See block **1702**. In the implementations depicted here, as the wearable fitness monitoring device determines that it is worn on the wrist, it maintains in the operational mode of light probing. If the heart monitor determines that the wearable device is not worn by the user, e.g., an off-wrist state is detected, the heart rate monitor switches into a low power state where it does not emit or detect light pulses, thereby saving electricity for the wearable device. See block **1704**. In the implementation depicted here, the wearable device may remain in the low power state or return to the light probing state, which may be regulated by the user's motion. In the implementation depicted here, if the heart rate monitor is in a low power state, it remains in such a state if no motion is detected. However, it returns to the light probing state when motion is detected indicating that the user is likely wearing the wearable fitness monitoring device. This motion regulated low power state avoids the need to use a light source and light detector to regulate the heart rate monitor, enabling further power saving. Motion detection for worn detection mode may be implemented by any one of the motion detectors suitable for a wearable device as described above. For instance, the motion detection may be implemented by an algorithm detecting stillness or motion from data generated by a motion sensor. Another example can use a motion sensor's innate interrupt for waking up the sensor, which can trigger the worn detection.

In the implementation depicted in FIG. **17**A, the heart rate monitor may measure heart rate or other heartbeat waveform related signals concurrently when it performs the light probing function depicted by block **1702**. The depicted light probing mechanism of 1702 determines whether the heart rate monitor should remain in the light probing mode and continue performing the heart monitoring function. The same light probing mechanism also determines whether the heart rate monitor should exit light probing and heart rate monitoring. As shown in FIG. **17**B, separate light probing mechanisms may be used for off-wrist detection to exit PPG heart rate monitoring and for on-wrist detection to enter PPG heart rate monitoring.

In some embodiments, the light probing mode for detecting "on-wrist" state, as depicted in block **1708** of FIG. **17**B, may emit light pulses in a relatively low intensity for a percentage of time. If the light emitted by the light source interacts with the user's skin or other tissues, the reflected or scattered light will be detected by the photodetector of the heart rate monitor. When this occurs, the heart rate monitor enters a normal power state as depicted by block **1706**. When this does not occur, the heart rate monitor continues light probing for a particular time period. If a specific time period has elapsed and no user interaction is detected by the light probing, the wearable device enters a low power state as depicted in Block **1710**.

The heart rate monitor in the normal power state performs both a heart rate monitoring function and a worn detection probing function, as shown in Block **1706**. The light probing mechanism for unworn detection of block **1706** can operate at relatively high power compared to that of worn-detection in block **1708** in some embodiments. In some embodiments, the function of **1708** is implemented in two states: one when entered from the off-wrist state and a different function when entered from the on-wrist state. This embodiment will be described in more detail below. In other embodiments, similar light pulses may be used for detecting transitions to unworn and for detecting transitions to worn. In some embodiments, different analyses may be applied to unworn detection or worn detection. For instance, unworn detection may be triggered by specific intensity variation pattern of detected light pulses, while worn detection may be triggered by intensity of detected light pulses. Examples of emission and detection of light pulses for unworn/worn detection are further described below.

The light probing mechanism of **1706** may determine whether the BMD is off-wrist (or unworn). If not, it remains in the normal power state to perform heart signal monitoring. If off-wrist state is detected, it stops PPG heart rate monitoring, exiting normal power mode and returning to the light probing mode of block **1708**. After the wearable device has been in light probing mode of **1708** for a particular period without detecting being worn, the wearable device enters the lower power state of block **1710**. The wearable device remains in the lower power state if no user motion is detected. It returns to the light probing state of **1708** if user motion is detected.

FIG. **18**A shows a process flow chart according to some embodiments of the disclosure, where a wearable fitness monitoring device having the heart rate monitor operates in different modes in energy efficient ways. In various embodiments as further described below, the heart rate monitor operates in different modes by emitting light pulses using a light source such as one or more LEDs, and detecting light after it interacts with the user's skin or other tissue. The characteristics of the emitted and detected light pulses are further described hereinafter.

In the embodiment depicted here, the wearable fitness monitoring device starts by detecting motion of the device. If no motion is detected, the device remains in the motion detection mode. See block **1802**. If the device detects motion it begins operating the heart rate monitor in a "worn detection mode" that is configured to detect the device has transitioned from an unworn to a worn state. The operation in the second mode may include pulsing light by a light source (e.g., an LED) and detecting the light after it interacts with the user's skin and/or tissues. See block **1804**. Within a defined time after entering the second mode, the device determines whether the heart rate monitor detects that the device has transitioned to a worn state. See block **1806**. If not, the device ends the worn detection mode, see block **1807**, and returns to the motion detection operation of block **1802**. If the device detects a transition to a worn state, it begins operating the heart rate monitor in a first mode that is configured to measure heartbeat waveform or other heart related signals of the user. See block **1808**.

The second mode of block **1804** corresponds to a worn detection mode as described elsewhere herein. In one implementation of FIG. **18**A, the worn detection mode can be implemented the same way as a second mode configured to detect transition to unworn state as shown in block **1810**. An alternative embodiment described below related to FIG. **18**B implements worn detection mode and unworn detection mode as two different modes.

As the heart rate monitor operates in the first mode of block **1808**, it detects pulses of light that interact with the user's tissue, capturing signal variation caused by heartbeat related blood flow in the capillary vessels of the user. In some embodiments, the heart rate monitor can measure other information related to heartbeat waveform as described above. Meanwhile, the device periodically and temporarily operate the heart rate monitor in the second mode to detect that the device has transitioned from a worn state to an unworn state, while also operating in the first mode to detect heart rate. See block **1810**. As the heart rate monitor operates in the second mode, the device determines whether the device has transi-

tioned to an unworn state, see block **1812**. If not, it continues to operate in both the first mode and the second mode as depicted in block **1810**. If yes, the device ends the first mode for monitoring heartbeat waveform signal. See block **1814**. At this point, the device returns the heart rate monitor to operate in the motion detection mode of block **1802**.

FIG. **18**B shows a process flow chart according to some embodiments of the disclosure. The process of FIG. **18**B is similar to that of FIG. **18**A, but presented with a slightly different focus, starting with concurrent operation of a first mode for detecting heart signals and a second mode for detecting an unworn state. See block **1822**, which may correspond to block **1810** of FIG. **18**A. The process of FIG. **18**B implements two different modes for unworn detection to automatically turn off heart rate monitoring (see the second mode in block **1822**) and worn detection to turn on heart rate monitoring (see the worn detection mode in block **1832**). In some implementations, the process of FIG. **18**A may use the same mechanism to detect proximity of user's body to turn on (see the worn detection mode of block **1804**) and off the heart rate monitoring (see the second mode of block **1810**).

In the process shown in FIG. **18**B, the wearable device operates the heart rate monitor in a first mode to detect heart rate or other heartbeat waveform characteristics. Concurrently, the heart rate monitor operates in a second mode to detect user proximity. See block **1822**. In the embodiments depicted here, the second mode is implemented to determine whether the heart rate monitor has transitioned to an unworn (or off-wrist) state. See block **1824**. If the device has not transitioned to an unworn state, the device continues to operate the heart rate monitor in both the first mode and the second mode in the operation of block **1822**. If the second mode determines that the heart rate monitor is unworn, the device automatically stops the heart rate monitor operation in the first mode. See block **1826**. This operation helps to conserve energy by automatically turning off the heart rate monitor when the device is not worn by the user. In some embodiments, the device enters a low-power state that does not monitor heart rate or probe user proximity (also stopping the second mode operation to further conserve energy, not shown in the flowchart).

In the process depicted in FIG. **18**B, the wearable device performs motion detection after stopping the first mode of heart signal monitoring, the motion detection providing a trigger for automatically turning on the heart rate monitoring function when necessary. See block **1828**. As mentioned elsewhere herein, the motion detection may be implemented by different hardware and software. If no motion is detected, the device remains in a low-power state. See block **1830**. If motion is detected, which indicates a possibility that the user is interacting with the device, the device starts operating in a worn detection mode that is designed to determine whether the device is likely worn by the user. See block **1832**. If the worn detection mode of the heart rate monitor determines that it is not worn, the device returns to the motion detection mode. However, if the heart rate monitor determines that the device is worn by the user, the device returns to the operation of block **1822** to concurrently operate the heart rate monitor in the first mode to detect heartbeat and in the second mode to detect user proximity (transition to an unworn state). See block **1834**. It should be understood that while the description of FIGS. **18**A and **18**B present starting and ending points for the device operations, the process may be implemented continuously and can start and end at any point in the disclosed flow charts. In some implementations, the starting and ending points are entered when the user manually turns the device on and off.

As mentioned above, the heart rate monitor of the wearable device includes an optical heart rate monitor in some embodiments. While the heart rate monitor operates in different modes, all modes involve emitting light pulses and detecting the same pulses after they interact with the user's tissues. The different modes may employ different light pulses and/or different processes for interpreting detected pulses. FIG. **18**C shows a cartoon of light pulses that are used to provide data for heart rate vs. the light pulses for probing proximity of the user's body in some embodiments. As in the shown embodiments, the heart rate monitor emits light pulses for both a heart rate data stream and a probing data stream. The heart rate data stream as depicted in this embodiment has a lower frequency, e.g., of 25 Hz (or 40 ms between two consecutive pulses), while the probing stream has a higher frequency, e.g., of 100 Hz (or 10 ms between two consecutive pulses). One skilled in the art appreciates that different frequencies and amplitudes may be used for the two data streams, while keeping the two data streams separable. In certain embodiments, the higher frequency is about 2 to 5 times greater than the lower frequency, or about 2 to 4 times greater. The two different frequencies of the light pulses allow the heart rate monitor to emit and detect two different signals simultaneously. The heart rate data stream allows the heart rate monitor to determine the heart rate signal of the user. The probing data stream allows the heart rate monitor to determine whether or not the device is in near proximity to the user's body. In some embodiments, the heart rate data stream may operate continuously in a first mode, while the probing stream operates periodically in a second mode. For instance, the probing data stream may operate for 120 ms every 1000 ms (one second). In some embodiments, the heart rate monitor operates the probing stream for less than about 50% of the time when it operates the heart rate data stream. In other embodiments, that percentage may be less than about 40%, 30%, 20%, 10%, or 5%.

In some embodiments, as shown in the example here, the heart rate data stream and the probing data stream are in phase, such that some pulses from one stream coincide with some pulses in another stream. This arrangement may help to reduce the number of pulses of light, thereby saving energy. In other embodiments, as shown in the following examples, two data streams are off phase, which may provide data streams that are more readily separable.

FIG. **18**D shows another cartoon of light pulses that can be used to provide data for heart rate vs. the light pulses for probing proximity of the user's body in some embodiments. The light pulses for heart rate data stream depicted here is similar to that in FIG. **18**C. However the probing data stream here has variable intensity, while the probing data stream in FIG. **18**C has fixed intensity. The probing data stream shown here may also be used to detect user skin characteristics in some embodiments as further described in the next section. In the example shown here, the probing data stream includes 8 pulses at 100 Hz, among which four have variable intensities. In some embodiments not shown here, fewer pulses may have variable intensities, e.g., only two pulses have variable intensities. In some embodiments, even one pulse may be sufficient for probing. In this example, two of the pulses have relatively low intensities and are different from each other. For instance, they may have values of about 0.02 to 0.04 mW for the lower intensity pulse and about 0.025 to 0.05 mW for the higher intensity pulse. The difference between the two pulses is indicated as D1 in the figure and may be in the neighborhood of about 0.002 to 0.005 mW. Two of the pulses have relatively high intensities and are different from each other. For instance, they can have values of about 0.1 to 0.11 mW for the

lower intensity pulse and about 0.14 to 0.15 mw for the higher intensity pulse. In other embodiments, the intensity values may be adjusted. As an additional example, a lower intensity pair of pulses may have intensities in mW of about 0.01 to 0.03 (e.g., about 0.021) and 0.025 to 0.035 (e.g., about 0.027), while a higher intensity pair may have pulse intensities of about 0.15 to 0.17 (e.g., about 0.16) and about 0.17 to 0.19 (e.g., about 0.175).

The difference between the two high intensity pulses is indicated as D2. The difference between the two pairs is labeled as D3. Additionally, four of the eight pulses have an intermediate and constant intensity. The specific numbers and intensities for the different pulses may be adjusted to provide good signal to be measured and analyzed. In some embodiments, the values of D1 and D2 are set to allow detection of a different response by the photodetector, which in turn allows analysis of light-user interaction, and user skin characteristics. The lower and higher intensities and the value of D3 are set to allow capturing light reflection in a range of likely conditions when the user is wearing the device: different skin colors, motions, sweat levels and compositions, ambient light conditions, etc. The intermediate intensity is set to allow capturing of baseline signal. In some embodiments, for instance, the lower intensity pulses provide good detection intensity for light colored skins; the high intensity pulses provide good detection for dark colored skins; and the intermediate intensity pulses provide good default values for baseline detection.

In some embodiments, the intensity of the light measured for any of the pulses may be used to determine worn and/or unworn state, as well as user skin characteristics. If the user is wearing the device and the light pulses interact with the user and then are detected, the device may infer the user's proximity from the intensity of the detected signal. For instance, if the device is worn, the detected intensity may be higher than unworn, or vice versa. Also, if the device is worn, a pulsing frequency consistent with the emitted pulses may be detected. If the device is worn, the difference of detected intensities between a pair of pulses can correlate with the difference in the emitted pulses (e.g., D1, D2, or D3). Such differences can provide an inference that the device is worn. In some embodiments, a detected difference between two pulses (e.g., the D1 pair) may be normalized by the difference between two constant pulses, then the normalized difference may be compared to a threshold value to determine if the device is worn. This analysis helps to eliminate inherent noise in detected light. In other implementations, the device determines the variance of the responses. When the variance is high, the device concludes that it is worn, and when the variance is low, the device concludes that it is not worn. In some embodiments further described in the next section, the slope and or trend of data points of emitted light value (e.g. intensity or power) vs. detected light may be used to obtain user skin response characteristics, which may then be used to calibrate emission power and/or gain of detection. In some embodiments, the device may have both the worn/unworn detection function and the skin characteristic calibration function as further described in the next section.

Some embodiments provide a method of operating a heart rate monitor of a wearable fitness monitoring device having a plurality of sensors. The method includes: (a) operating the heart rate monitor in a first mode while also operating in a second mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin, where the first mode is configured to determine one or more characteristics of a user's heartbeat waveform when the wearable fitness monitoring device is in near proximity to the user; (b) from

information collected in the second mode, determining that the heart rate monitor is not proximate to the user's skin; and (c) in response to determining that the heart rate monitor is not proximate to the user's skin, ending operating the heart rate monitor in the first mode. In some embodiments, the one or more characteristics of the user's heartbeat waveform include the user's heart rate.

In some embodiments, the wearable device includes a motion sensor, and the method further involving: prior to (c), determining from information output by the motion detecting sensor that the wearable fitness monitoring device has had been still for at least a defined period; and in response to detecting that the wearable fitness monitoring device has had been still for at least the defined period, performing (c). In some embodiments, prior to (a) while the first mode is not operating, the device (i) detects motion of the wearable fitness monitoring device using a motion detecting sensor and/or detecting proximity of the heart rate monitor to the user' skin by operating the heart rate monitor in a third mode; and (ii) initiates operation of the first mode of the heart rate monitor when the wearable fitness monitoring device is determined to be in near proximity to the user.

In some embodiments, the heart rate monitor operates in the second mode no more than about 50% of the time. In other embodiments, the percentage is no more than about 40%, 30%, 20%, or 10%.

In some embodiments, operating the heart rate monitor in the second mode involves pulsing a light source in the heart rate monitor at a second mode frequency and detecting light from the light source at the second mode frequency; and operating the heart rate monitor in the first mode involves pulsing the light source in the heart rate monitor at a first mode frequency and detecting light from the light source at the first mode frequency. In some embodiments, operating the heart rate monitor in the second mode involves emitting a succession of light pulses of variable intensity and determining whether detected light corresponding to the succession of light pulses has a variable response corresponding to the variable intensity of the emitted light pulses.

Some embodiments provide a method of operating a heart rate monitor of a wearable fitness monitoring device having a plurality of sensors. The method includes: (a) detecting motion of the wearable fitness monitoring device using the motion detecting sensor; (b) in response to detecting the motion in (a), operating the heart rate monitor in a worn detection mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin; and (c) upon determining via the worn detection mode that the wearable fitness monitoring device is proximate to the user's skin, operating the heart rate monitor in a first mode configured to determine one or more characteristics of the user's heartbeat waveform. In some embodiments, (a) is performed when the heart rate monitor is not operating or is operating in a low power mode. In some embodiments, the method involves, prior to (a): (i) operating the heart rate monitor in the first mode while also operating in a second mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin; (ii) from information collected in the second mode, determining that the heart rate monitor is not proximate to the user's skin; and (iii) in response to determining that the heart rate monitor is not proximate to the user's skin, ending operating the heart rate monitor in the first mode.

In some embodiments, the heart rate monitor operates in the worn detection mode no more than about 50% of the time. In other embodiments, the percentage is no more than about 40%, 30%, 20%, or 10%.

In some embodiments, operating the heart rate monitor in the worn detection mode includes: emitting light pulses from a light source in the heart rate monitor having a second frequency and/or phase; detecting light from the light source at the second frequency and/or phase; and determining whether the light detected at the second frequency and/or phase has an intensity and/or pattern indicating that the light from the light source has interacted with the user's skin. In some embodiments, the emitted light pulses have variable intensity. In some embodiments, the emitted light pulses include a succession of light pulses having variable intensity. In some embodiments, a first one of the succession of light pulses has an intensity at least 5 times greater than a second one of the succession of light pulses. In some embodiments, lower intensity pulses are emitted at about 0.05 to 0.5 mW (e.g., about 0.012 mW) and higher intensity pulses are emitted at about 0.5 to 2 mW (e.g., about 1.19 mW). In other embodiments, intensities may be adjusted according to applications and implementations. In some embodiments, the succession of light pulses include a first set of pulses having an intensity providing variable response when interacting with light skin, and where the succession of light pulses includes a second set of pulses having an intensity providing a variable response when interacting with dark skin.

Heart Rate Monitor with Automatic Calibration

In some embodiments, the disclosure provide methods and devices to accurately measure heartbeat waveform for different user characteristics, such as skin colors, motion, sweat, position, and physiologic state (e.g., skin thickness, body fat, etc.) of the users. FIG. **19**A shows two relationships between light intensity emitted by a light source of the heart rate monitor vs. the signal detected by the photodetector. Because darker skin has lower reflectance of light, the relations between photodetector reading and light pulse intensity, e.g., DAC, tends to have a lower slope than for paler skin. FIG. **19**B depicts the temporal modulation of the TIA signal, where the pattern of the modulation reflects heart beats that modulate the reflection and refraction of the capillary system of the user. In some embodiments, the signals for skin characterization may operate intermittently at higher frequency than the light pulses of the first mode for heart rate monitoring.

FIG. **19**C shows flowchart for a process of operating a heart rate monitor of a wearable fitness monitoring device by adjusting light emission power and/or light detection gain of the heart rate monitor. In various embodiments, the adjustments may be implemented by software, firmware or hardware. The process starts by emitting and detecting light pulses in the skin characterization mode. See block **1902**. In some embodiments, the light pulses used in the skin characterization mode may be similar or identical to those for worn and/or unworn detection modes as shown in FIG. **18**D. In other embodiments, the light pulses used in the skin characterization mode may have ramping intensities as shown in FIG. **19**D. In some embodiments, the light pulses for the skin characterization mode are in phase with the light pulses for the first mode configured to measure heartbeat waveform information. In other embodiments, the light pulses for the skin characterization mode and the pulses for the first mode are out of phase as shown in FIG. **19**D. FIG. **19**D shows light pulse signal patterns that may be used to regulate a heart rate monitor's light source intensity and/or light detection gain so as to accurately measure heart rate signals for users with different characteristics such as skin colors.

As depicted in FIG. **19**D, light pulses of constant intensity and lower frequency may be applied for generating pulses in a first mode for measuring heart rate, in a manner similar to that depicted in FIG. **18**B. Meanwhile, a second stream of light signals of various intensities may be used to detect skin reflection characteristics. As the reflection characteristics is detected and determined by the heart rate monitor, it may adjust light intensity and/or detection gain by the heart rate monitor, such that the optimal signal level and pattern may be measured by the heart rate monitor.

The process for adjusting the heart rate monitor further involves determining a slope of detected light value versus emitted light value some initial light pulses. See block **1904**. In some embodiments, various emitted light levels are provided for different slopes, which emitted light levels provide good heart rate monitoring performance for skin conditions having comparable slopes. The process then chooses a new emitted light value based on the determined slope, corresponding previously provided slopes and light intensity. See block **1906**. The new emitted light value is used for operating a first mode for heartbeat waveform measurements. See block **1908**.

The process further involves collecting more data points in the skin characterization mode (see block **1910**) and fitting a mathematical relationship to the collected more data points (see block **1912**). Various mathematical relationships may be applied depending on the data patterns between emitted intensity and detected intensity for different skin characteristics. In some embodiments, the mathematical relationship is linear as shown in FIG. **19**E. In other embodiments, the mathematical relationship is polynomial as shown in FIG. **19**F. Alternative mathematical relationship may be applied in other embodiments. The process further involves applying a preset detected light value known to provide good detection reading (e.g., light intensity or power) to the fitted relationship to obtain the corresponding emitted light value. The process then involves emitting light at the obtained emitted light value corresponding to the preset detected light value for operating the heart rate monitor in the first mode. See block **1914**. In some embodiments, the calibration process ends after the light is emitted at the obtained value. See block **1916**. In other embodiments, the calibration process may continuously and dynamically adjusts the emitted light intensity. In some embodiments, the calibration process may adjust the gain of the photodetector.

Some embodiments provide a method for adjusting at least one setting for operating a heart rate monitor in a wearable fitness monitoring device. The method involves: (a) pulsing a light source in the heart monitor in a skin characterization mode by emitting a succession of light pulses, at least some having variable intensity with respect to one another; (b) detecting a variation in intensity of light from the light pulses emitted in the skin characterization mode after the light has interacted with the user's skin; (c) determining a response characteristic of the user's skin from the variation in intensity of light detected in (b); and (d) using the response characteristic of the user's skin to adjust a gain and/or light emission intensity of the heart rate monitor operating in a first mode for detecting one or more characteristics of the user's heartbeat waveform.

In some embodiments, the response characteristic is dependent on an opacity value of the user's skin. In some embodiments, operating in the first mode and operating in the skin characterization mode are performed concurrently. In some embodiments, operating in the first mode and operating in the skin characterization mode concurrently involves periodically determining a response characteristic of the user's skin while continuously operating in the first mode. In some embodiments, operating in the skin characterization mode occurs no more than about 50% of the time, e.g., no more than about 40% of the time, or no more than about 30% of the time,

no more than about 20% of the time, no more than about 10% of the time, no more than about 5% of the time.

In some embodiments, operating in the first mode involves pulsing the light source in the heart rate monitor at a first frequency and detecting light from the light source, after the light has interacted with the user's skin, at the first frequency. Furthermore, operating in the skin characterization mode involves pulsing the light source in the heart rate monitor at a second frequency and detecting light from the light source at the second frequency.

There are many concepts and embodiments described and illustrated herein. While certain embodiments, features, attributes, and advantages have been described and illustrated herein, it should be understood that many others, as well as different and/or similar embodiments, features, attributes and advantages are apparent from the description and illustrations. As such, the above embodiments are merely provided by way of example. They are not intended to be exhaustive or to limit this disclosure to the precise forms, techniques, materials and/or configurations disclosed. Many modifications and variations are possible in light of this disclosure. It is to be understood that other embodiments may be utilized and operational changes may be made without departing from the scope of the present disclosure. As such, the scope of the disclosure is not limited solely to the description above because the descriptions of the above embodiments have been presented for the purposes of illustration and description.

Importantly, the present disclosure is neither limited to any single aspect nor embodiment, nor to any combinations and/or permutations of such aspects and/or embodiments. Moreover, each of the aspects of the present disclosure, and/or embodiments thereof, may be employed alone or in combination with one or more of the other aspects and/or embodiments thereof. For the sake of brevity, many of those permutations and combinations will not be discussed and/or illustrated separately herein.

What is claimed is:

1. A method of operating a heart rate monitor of a wearable fitness monitoring device comprising a plurality of sensors including the heart rate monitor and a motion detecting sensor, the method comprising:

(a) detecting motion of the wearable fitness monitoring device using the motion detecting sensor;

(b) in response to detecting the motion in (a), operating the heart rate monitor in a worn detection mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin; and

(c) upon determining via the worn detection mode that the wearable fitness monitoring device is proximate to the user's skin, operating the heart rate monitor in a first mode configured to determine one or more characteristics of the user's heartbeat waveform, and wherein operations (b) and (c) are carried out by a processor.

2. The method of claim **1**, wherein the heart rate monitor comprises an optical heart rate monitor.

3. The method of claim **2**, wherein the heart rate monitory comprises a photoplethysmographic sensor.

4. The method of claim **1**, wherein the one or more characteristics of the user's heartbeat waveform comprises the user's heart rate.

5. The method of claim **1**, wherein (b) comprises operating the heart rate monitor in the worn detection mode occurs no more than about 50% of the time.

6. The method of claim **1**, wherein

operating the heart rate monitor in the worn detection mode comprises pulsing a light source in the heart rate monitor at a worn detection mode frequency and detecting light from the light source at the worn detection mode frequency; and

operating the heart rate monitor in the first mode comprises pulsing the light source in the heart rate monitor at a first mode frequency and detecting light from the light source at the first mode frequency.

7. The method of claim **6**, wherein the worn detection mode frequency is greater than the first mode frequency.

8. The method of claim **1**, wherein operating the heart rate monitor in the worn detection mode comprises:

emitting light pulses from a light source in the heart rate monitor having a second frequency and/or phase;

detecting light from the light source at the second frequency and/or phase; and

determining whether the light detected at the second frequency and/or phase has an intensity and/or pattern indicating that the light from the light source has interacted with the user's skin.

9. The method of claim **8**, wherein the emitting light pulses from the light source comprises emitting a succession of light pulses having variable intensity.

10. The method of claim **9**, wherein a first one of the succession of light pulses has an intensity at least 5 times greater than a second one of the succession of light pulses.

11. The method of claim **9**, wherein the succession of light pulses comprises a first set of pulses having an intensity providing variable response when interacting with light skin, and wherein the succession of light pulses comprises a second set of pulses having an intensity providing a variable response when interacting with dark skin.

12. The method of claim **1**, wherein operating the heart rate monitor in the worn detection mode comprises:

emitting a succession of light pulses of variable intensity; and

determining whether detected light corresponding to the succession of light pulses has a variable response corresponding to the variable intensity of the light pulses.

13. The method of claim **1**, wherein the motion detecting sensor comprises an accelerometer, a magnetometer, an altimeter, a GPS detector, gyroscope, or a combination of any of these.

14. The method of claim **1**, further comprising:

determining from information output by the motion detecting sensor that the wearable fitness monitoring device has been still for at least a defined period; and

in response to detecting that the wearable fitness monitoring device has been still for at least the defined period, powering down the device.

15. The method of claim **1**, wherein (a) is performed when the heart rate monitor is not operating or is operating in a low power mode.

16. The method of claim **15**, wherein (a) comprises detecting an output from the motion detecting sensor, wherein the output exceeds a defined threshold.

17. The method of claim **15**, further comprising prior to (a):

(i) operating the heart rate monitor in the first mode while also operating in a second mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin;

(ii) from information collected in the second mode, determining that the heart rate monitor is not proximate to the user's skin; and

(iii) in response to determining that the heart rate monitor is not proximate to the user's skin, ending operating the heart rate monitor in the first mode.

18. A wearable fitness monitoring device comprising:

a motion sensor configured to provide output corresponding to motion by a user wearing the fitness monitoring device;

a photoplethysmographic sensor comprising (i) a periodic light source, (ii) a photo detector positioned to receive periodic light emitted by the periodic light source after interacting with a user's skin, and (iii) circuitry determining a user's heart rate from an output of the photo detector; and

control logic configured to:

(a) detect motion of the wearable fitness monitoring device using the motion detecting sensor;

(b) in response to detecting the motion in (a), operate the heart rate monitor in a worn detection mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin; and

(c) upon determining via the worn detection mode that the wearable fitness monitoring device is proximate to the user's skin, operate the heart rate monitor in a first mode configured to determine one or more characteristics of the user's heartbeat waveform.

19. The wearable fitness monitoring device of claim **18**, wherein the one or more characteristics of the user's heartbeat waveform comprises the user's heart rate.

20. The wearable fitness monitoring device of claim **18**, wherein operating the heart rate monitor in the worn detection mode occurs no more than about 50% of the time.

21. The wearable fitness monitoring device of claim **18**, wherein

operating the heart rate monitor in the worn detection mode comprises pulsing a light source in the heart rate monitor at a worn detection mode frequency and detecting light from the light source at the worn detection mode frequency; and

operating the heart rate monitor in the first mode comprises pulsing the light source in the heart rate monitor at a first mode frequency and detecting light from the light source at the first mode frequency.

22. The wearable fitness monitoring device of claim **21**, wherein the worn detection mode frequency is greater than the first mode frequency.

23. The wearable fitness monitoring device of claim **18**, wherein operating the heart rate monitor in the worn detection mode comprises:

emitting light pulses from a light source in the heart rate monitor having a second frequency and/or phase;

detecting light from the light source at the second frequency and/or phase; and

determining whether the light detected at the second frequency and/or phase has an intensity and/or pattern indicating that the light from the light source has interacted with the user's skin.

24. The wearable fitness monitoring device of claim **23**, wherein the emitting light pulses from the light source comprises emitting a succession of light pulses having variable intensity.

25. The wearable fitness monitoring device of claim **24**, wherein a first one of the succession of light pulses has an intensity at least 5 times greater than a second one of the succession of light pulses.

26. The wearable fitness monitoring device of claim **24**, wherein the succession of light pulses comprises a first set of pulses having an intensity providing variable response when interacting with light skin, and wherein the succession of light pulses comprises a second set of pulses having an intensity providing a variable response when interacting with dark skin.

27. The wearable fitness monitoring device of claim **18**, further comprising:

determining from information output by the motion detecting sensor that the wearable fitness monitoring device has been still for at least a defined period; and

in response to detecting that the wearable fitness monitoring device has been still for at least the defined period, powering down the device.

28. The wearable fitness monitoring device of claim **18**, wherein (a) is performed when the heart rate monitor is not operating or is operating in a low power mode.

29. The wearable fitness monitoring device of claim **28**, wherein (a) comprises detecting an output from the motion detecting sensor, wherein the output exceeds a defined threshold.

30. The wearable fitness monitoring device of claim **28**, wherein the control logic is further configured, prior to (a), to:

(i) operate the heart rate monitor in the first mode while also operating in a second mode configured to detect near proximity of the wearable fitness monitoring device to a user's skin;

(ii) from information collected in the second mode, determine that the heart rate monitor is not proximate to the user's skin; and

(iii) in response to determining that the heart rate monitor is not proximate to the user's skin, end operating the heart rate monitor in the first mode.

* * * * *

EXHIBIT B

US008868377B2

(12) **United States Patent**
Yuen et al.

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(45) **Date of Patent: Oct. 21, 2014**

(54) **PORTABLE MONITORING DEVICES AND METHODS OF OPERATING SAME**

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See application file for complete search history.

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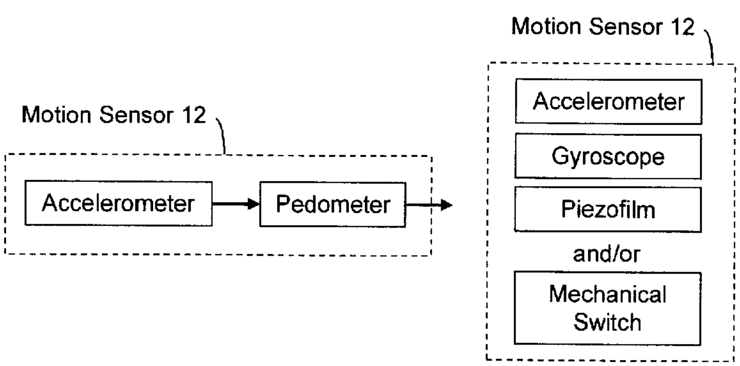
(57) **ABSTRACT**

The present inventions, in one aspect, are directed to a portable activity monitoring device comprising a housing having a physical size and shape that is adapted to couple to the user's body, a plurality of sensors (for example, motion sensor and altitude sensor) disposed in the housing. The monitoring device may further include processing circuitry, disposed in the housing and electrically coupled to the plurality of sensor, to calculate the activity points corresponding to the physical activity of the user using the sensor data, wherein the activity points correlate to an amount and intensity of the physical activity of the user, and output the data which is representative of the activity points. The monitoring device may also include a display, coupled to the processing circuitry, may output the data which is representative of the activity points to the user.

29 Claims, 50 Drawing Sheets



Related U.S. Application Data

of application No. 13/667,242, filed on Nov. 2, 2012, now Pat. No. 8,463,576, which is a division of application No. 13/469,033, filed on May 10, 2012, now Pat. No. 8,311,770, which is a division of application No. 13/249,155, filed on Sep. 29, 2011, now Pat. No. 8,180,592, which is a division of application No. 13/156,304, filed on Jun. 8, 2011.

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USPC **702/160**

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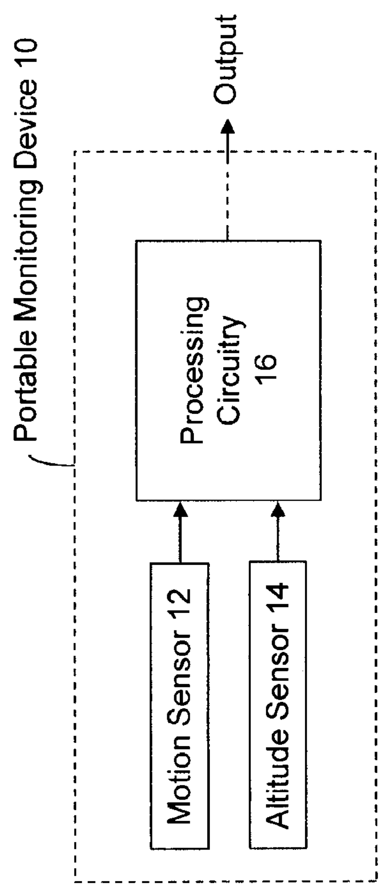


FIGURE 1A

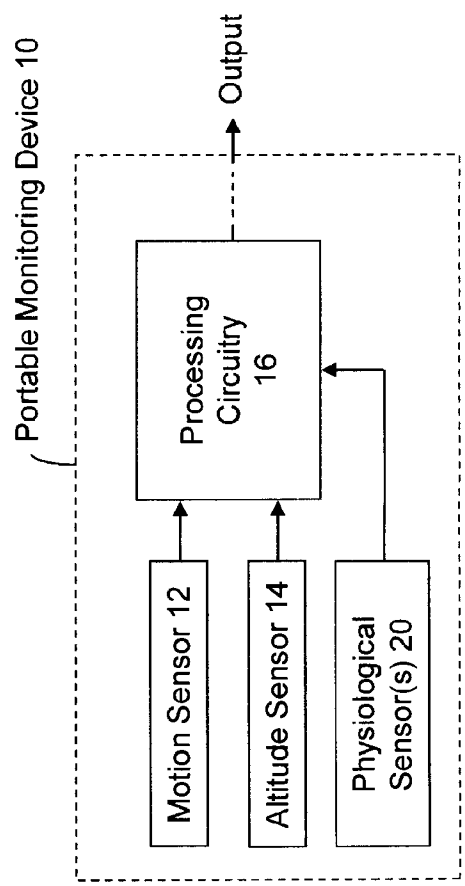


FIGURE 1B

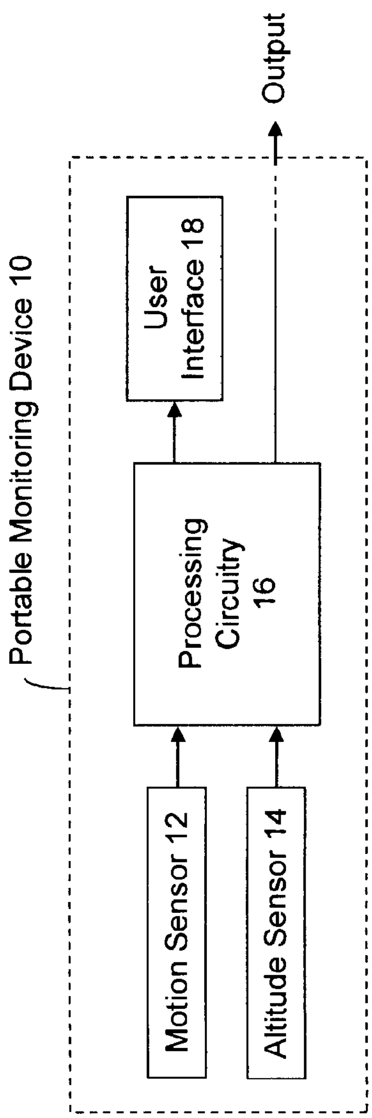


FIGURE 1C

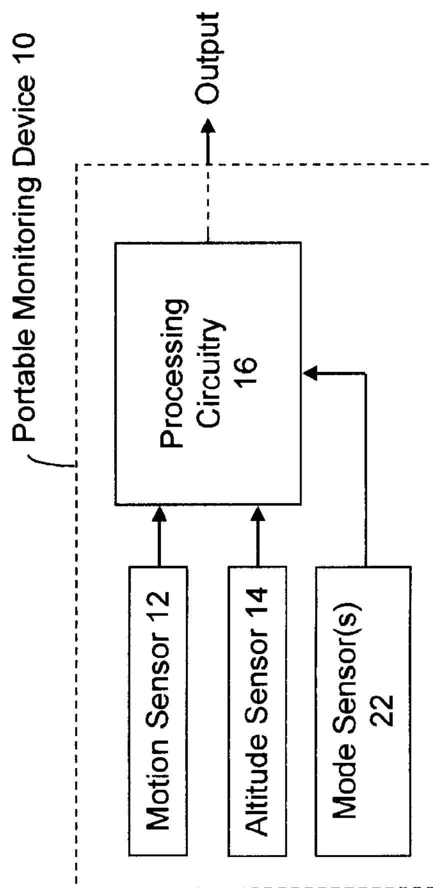


FIGURE 1D

FIGURE 1E

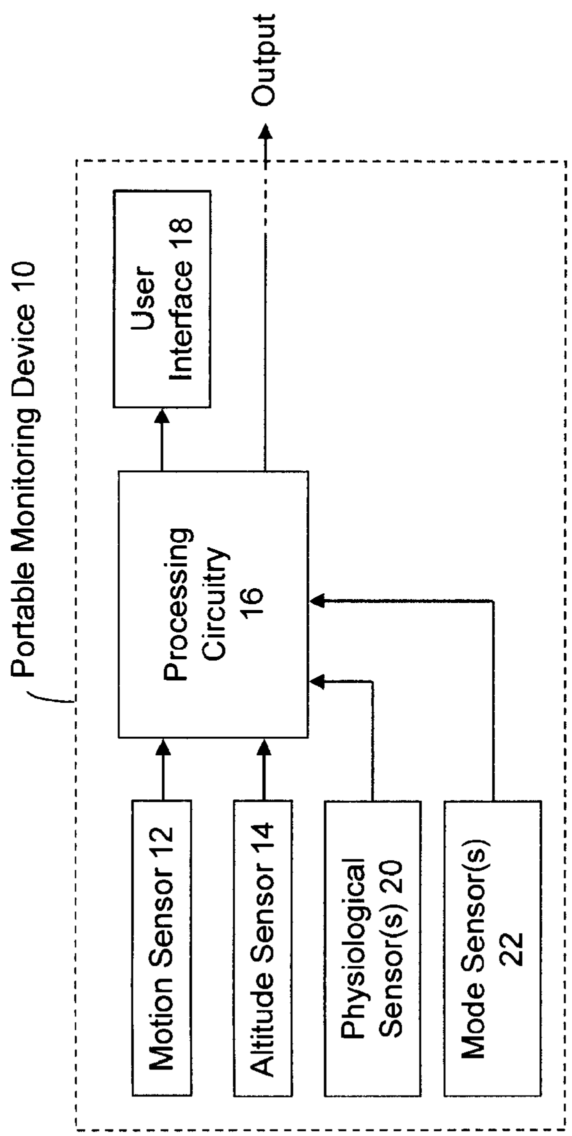
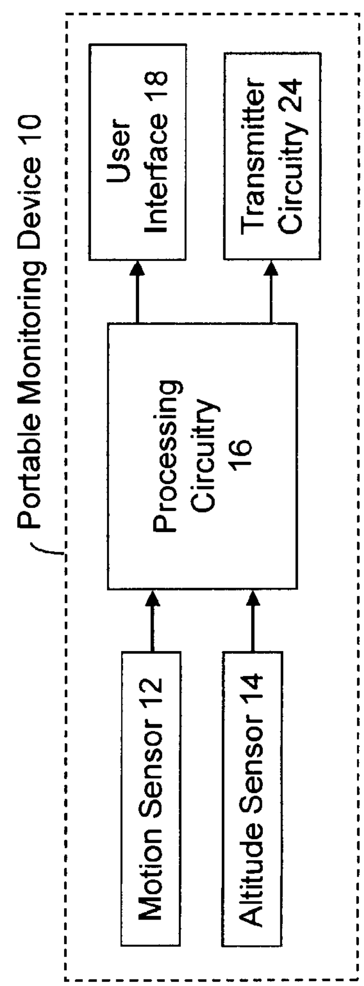


FIGURE 1F



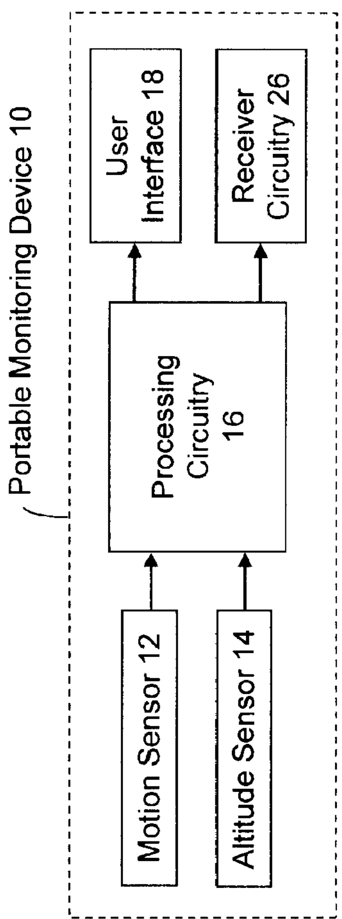


FIGURE 1G

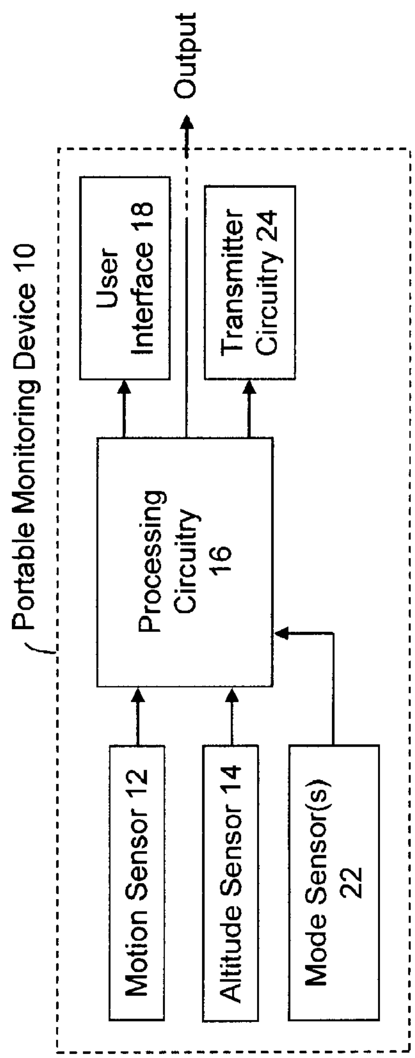


FIGURE 1H

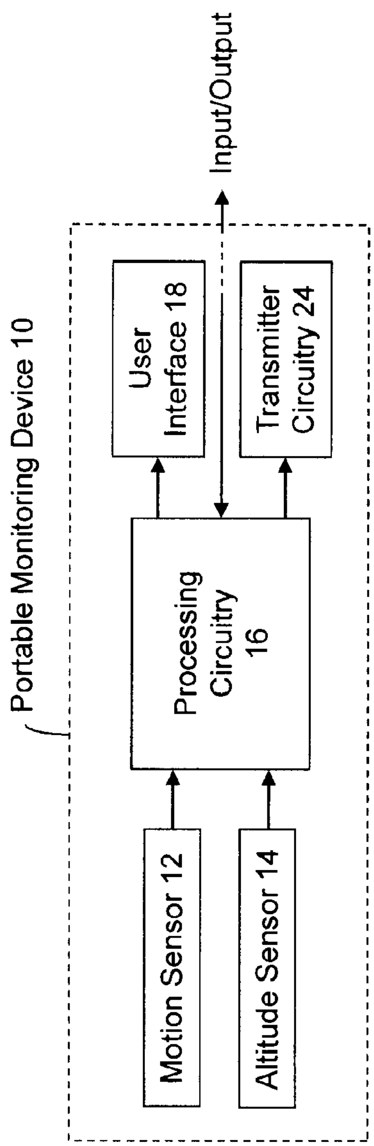


FIGURE 1I

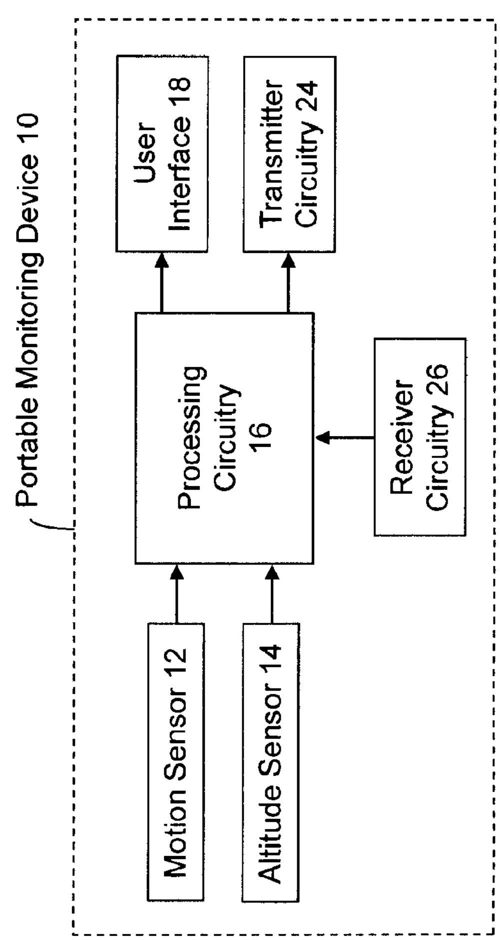


FIGURE 1J

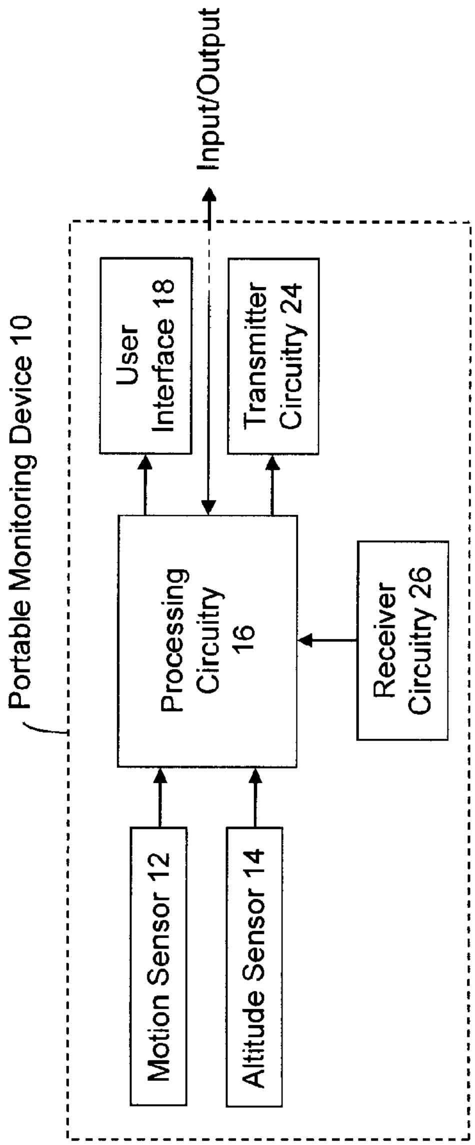


FIGURE 1K

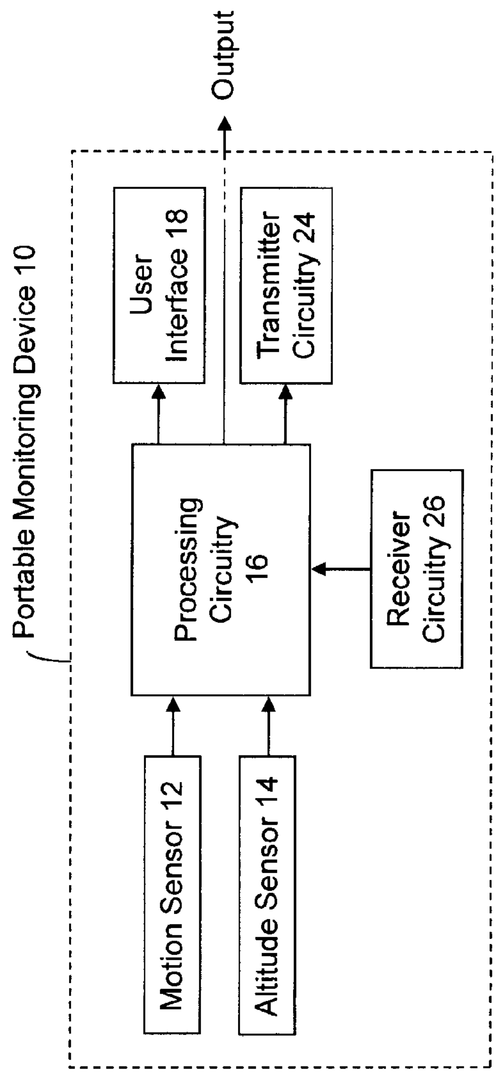


FIGURE 1L

FIGURE 1M

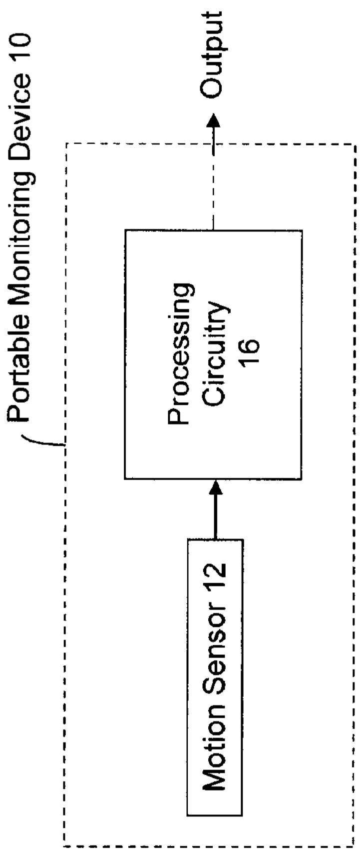


FIGURE 1N

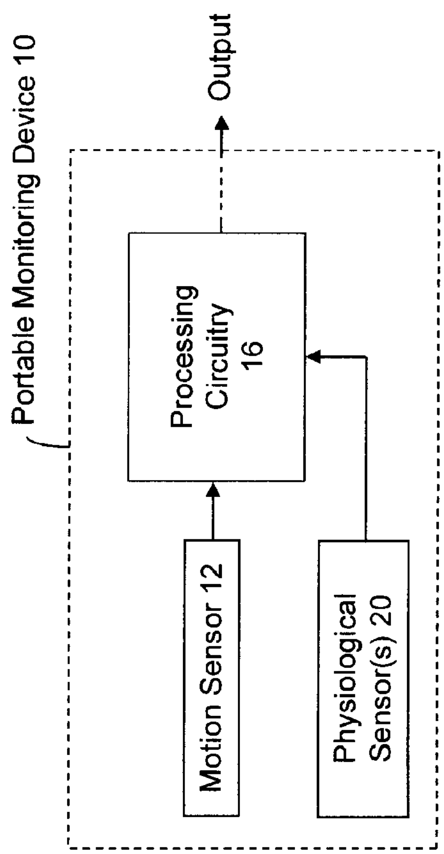
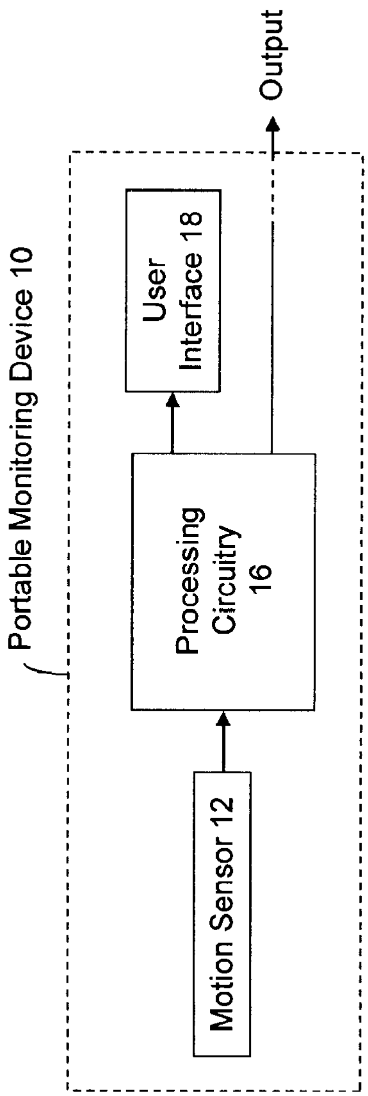


FIGURE 1O



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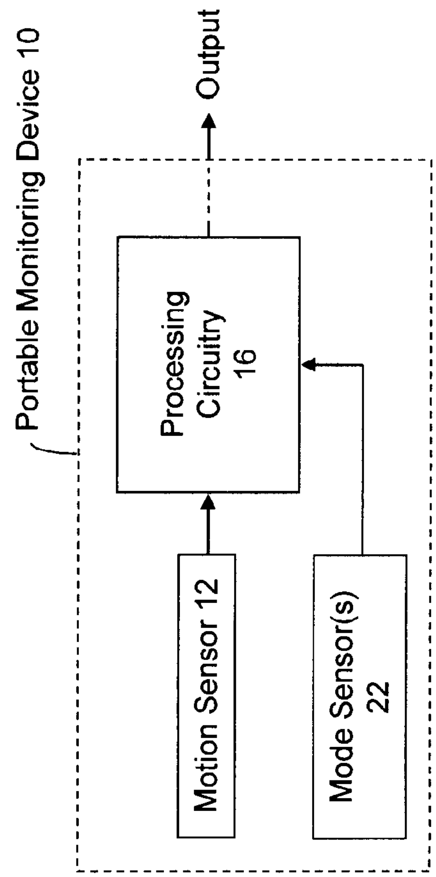


FIGURE 1Q

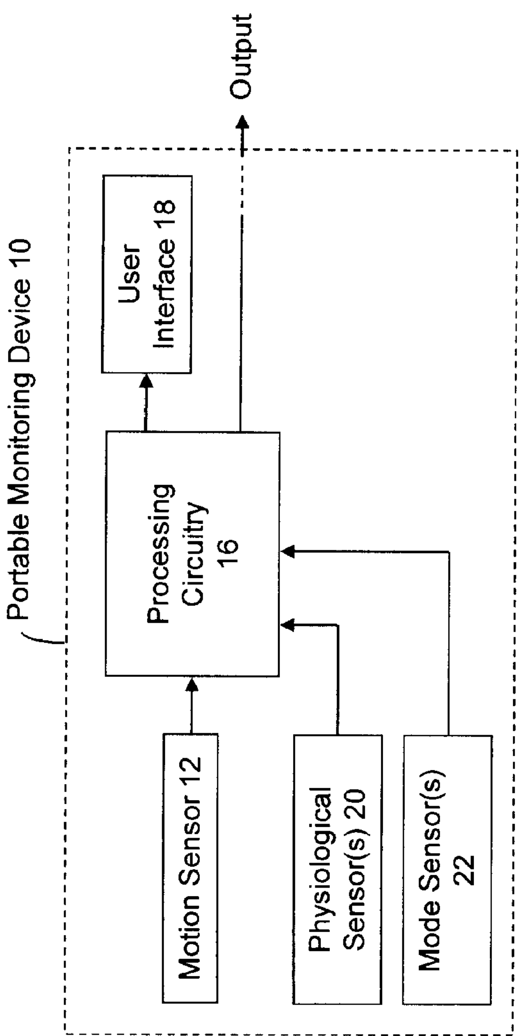


FIGURE 1R

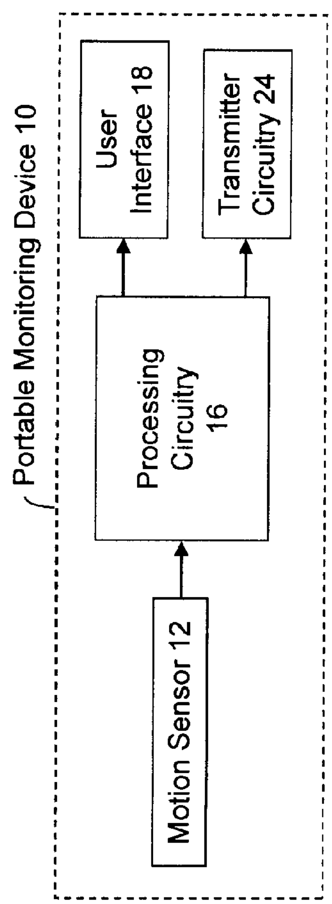


FIGURE 1S

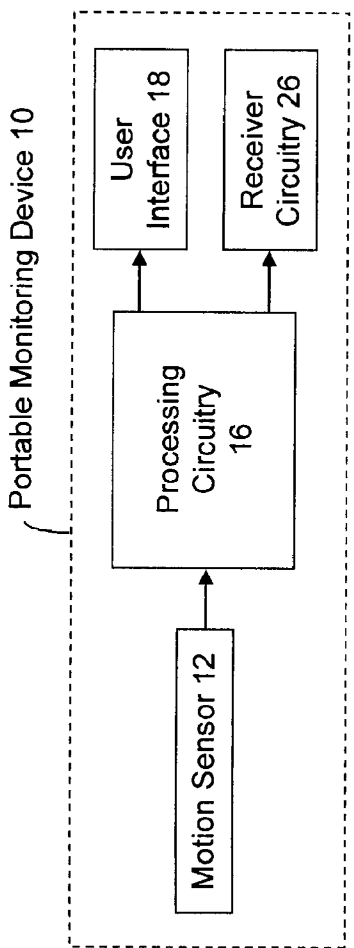
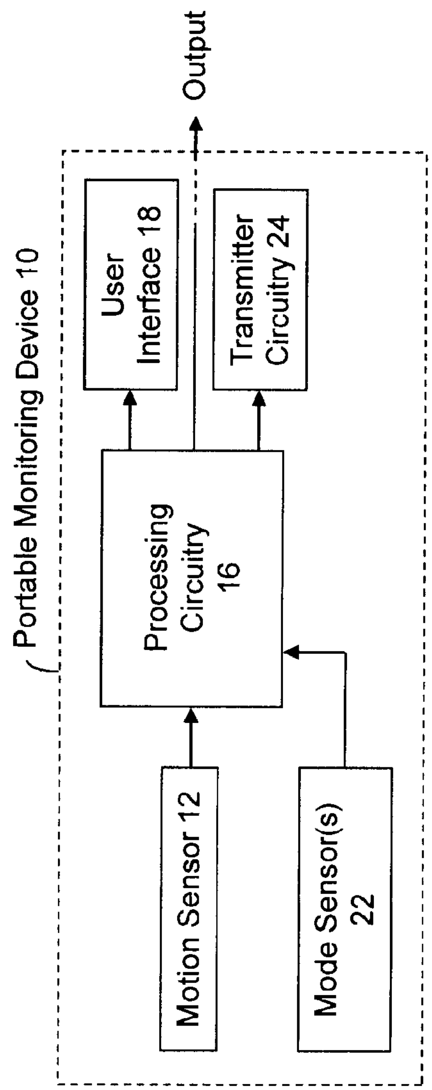


FIGURE 1T



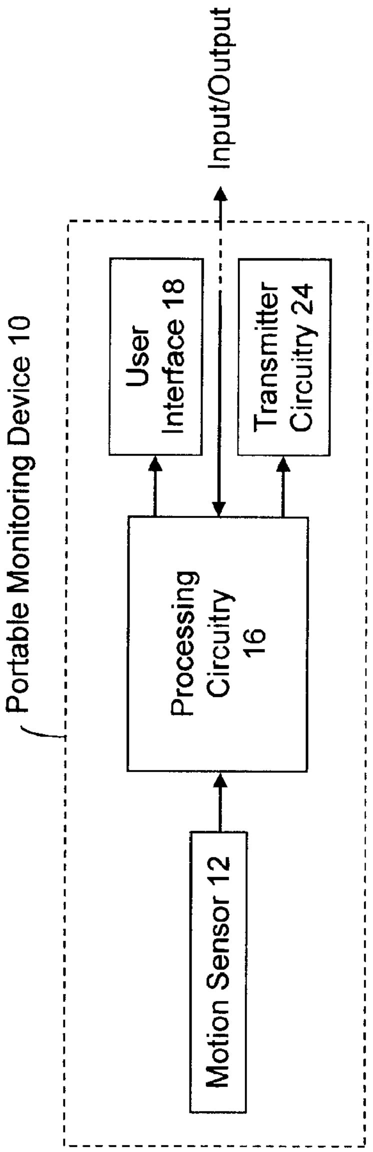


FIGURE 1U

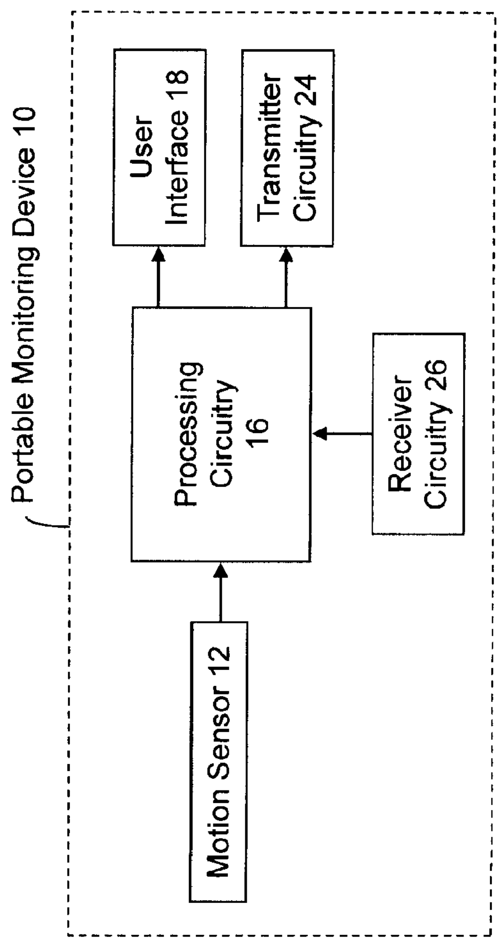


FIGURE 1V

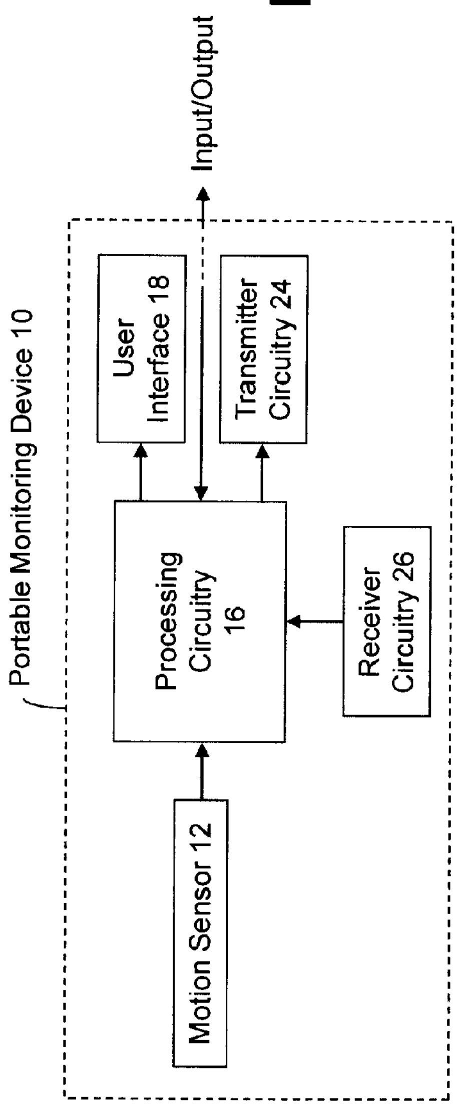


FIGURE 1W

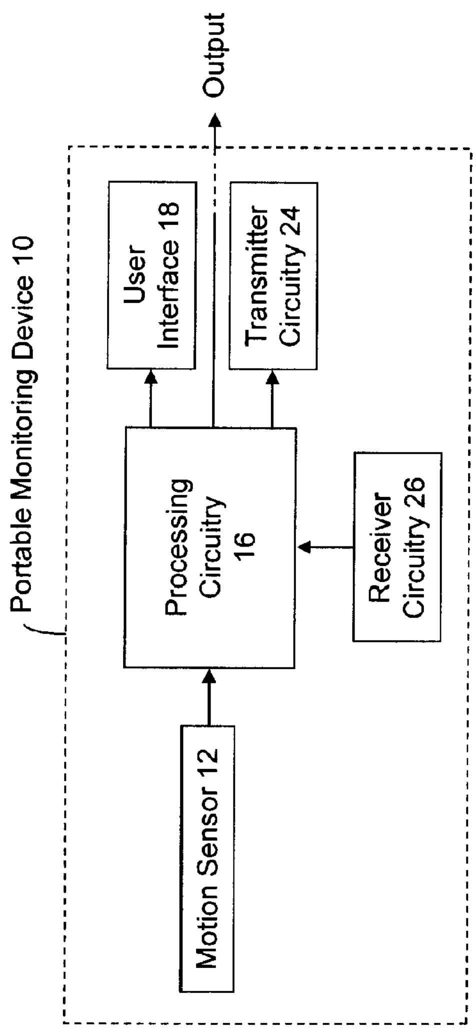


FIGURE 1X

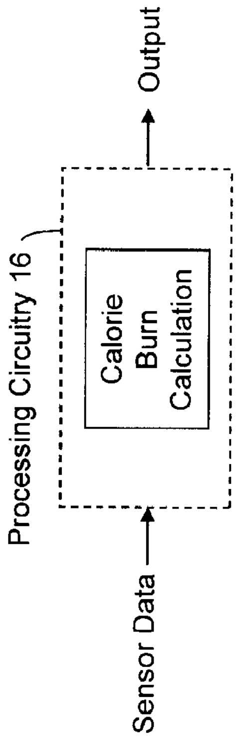


FIGURE 2

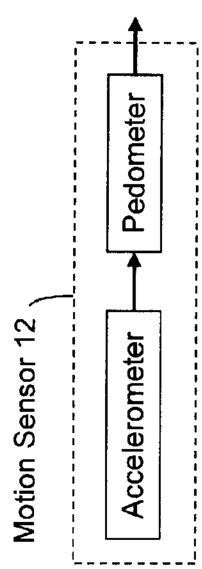


FIGURE 3A

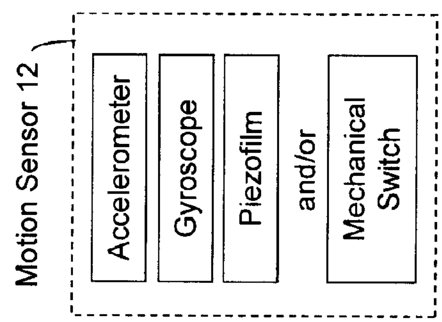


FIGURE 3B

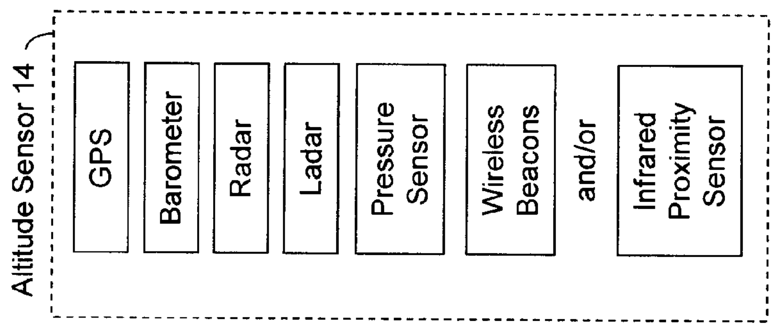


FIGURE 3C

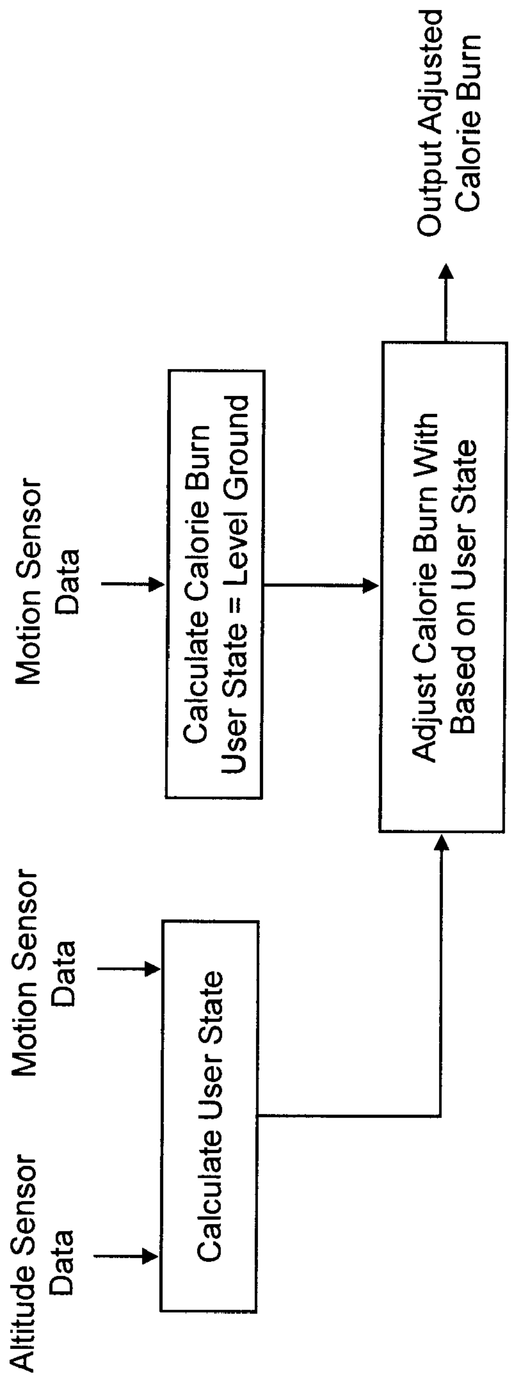

Altitude Sensor Data
Motion Sensor Data
Calculate User State
Motion Sensor Data
Calculate Calorie Burn User State = Level Ground
Adjust Calorie Burn With Based on User State
Output Adjusted Calorie Burn

FIGURE 4A

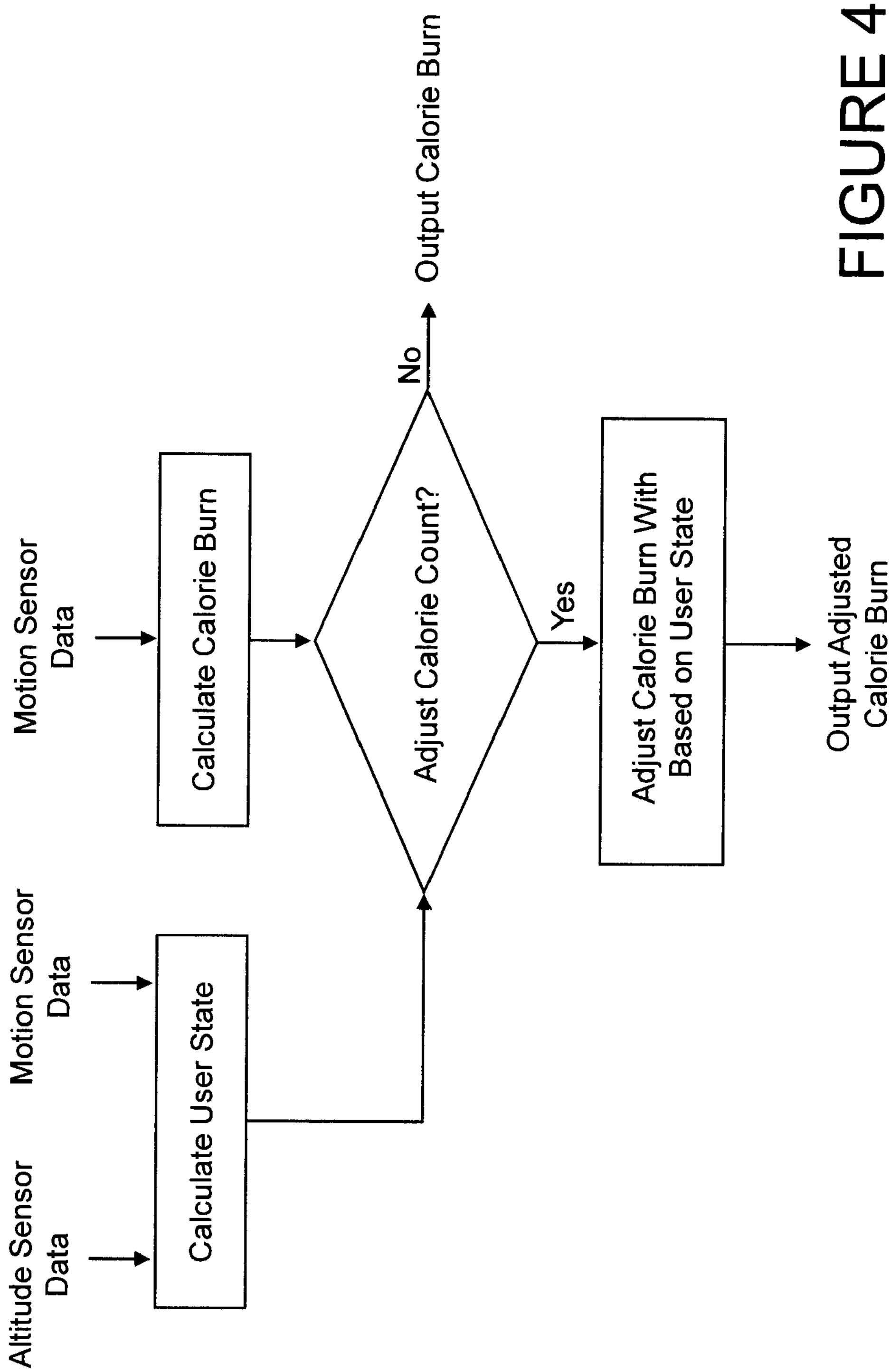
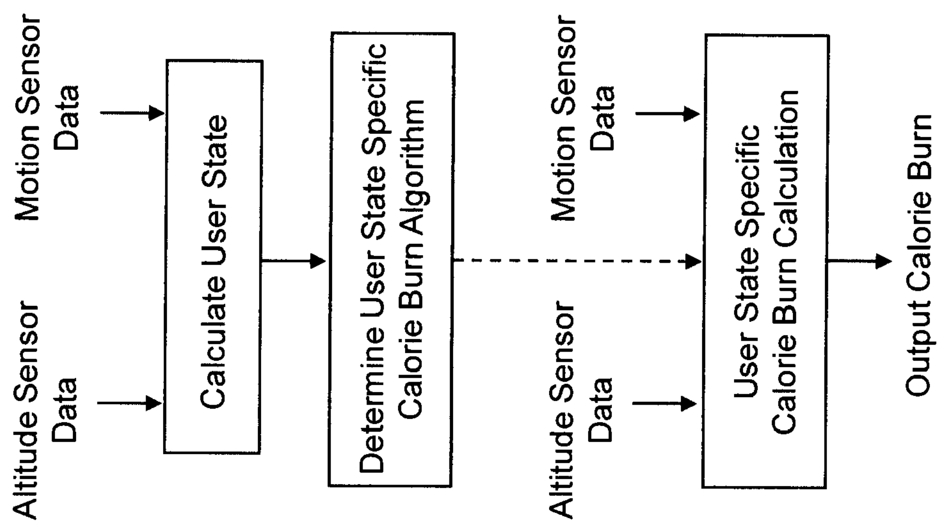

Motion Sensor Data
Calculate Calorie Burn
Altitude Sensor Data
Motion Sensor Data
Calculate User State
Adjust Calorie Count?
No
Output Calorie Burn
Yes
Adjust Calorie Burn With Based on User State
Output Adjusted Calorie Burn

FIGURE 4B

FIGURE 4C


Altitude Sensor Data
Motion Sensor Data
Calculate User State
Determine User State Specific Calorie Burn Algorithm
Altitude Sensor Data
Motion Sensor Data
User State Specific Calorie Burn Calculation
Output Calorie Burn

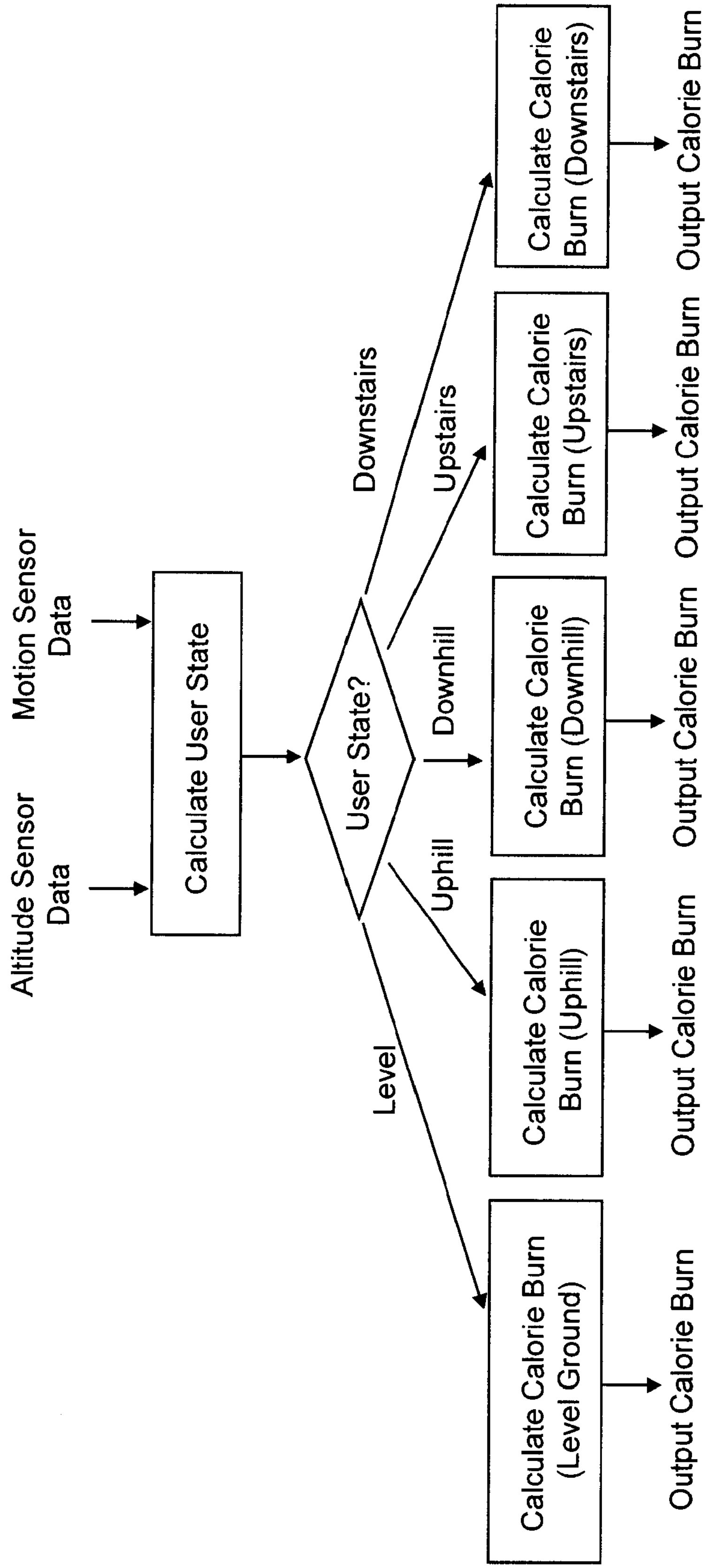

Altitude Sensor Data
Motion Sensor Data
Calculate User State
User State?
Level
Uphill
Downhill
Upstairs
Downstairs
Calculate Calorie Burn (Level Ground)
Calculate Calorie Burn (Uphill)
Calculate Calorie Burn (Downhill)
Calculate Calorie Burn (Upstairs)
Calculate Calorie Burn (Downstairs)
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn

FIGURE 4D

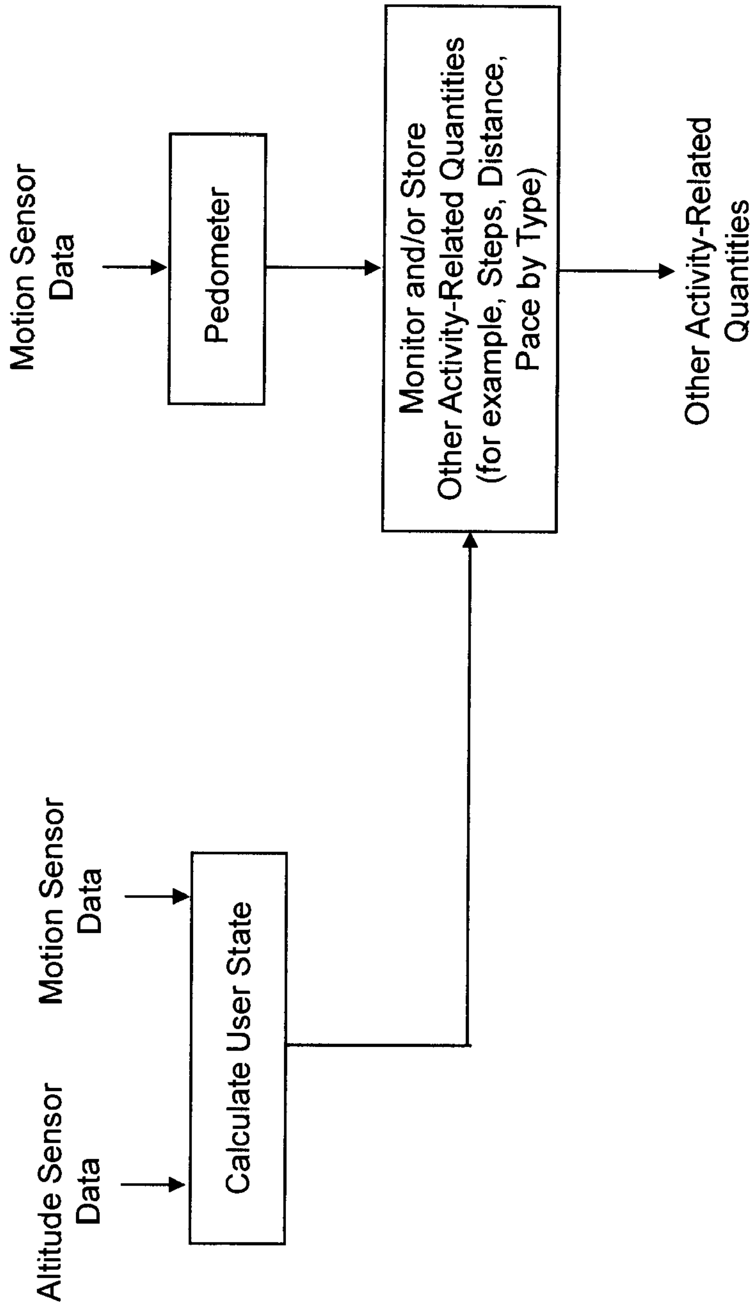

Motion Sensor Data
Pedometer
Monitor and/or Store Other Activity-Related Quantities (for example, Steps, Distance, Pace by Type)
Other Activity-Related Quantities
Altitude Sensor Data
Motion Sensor Data
Calculate User State

FIGURE 4E

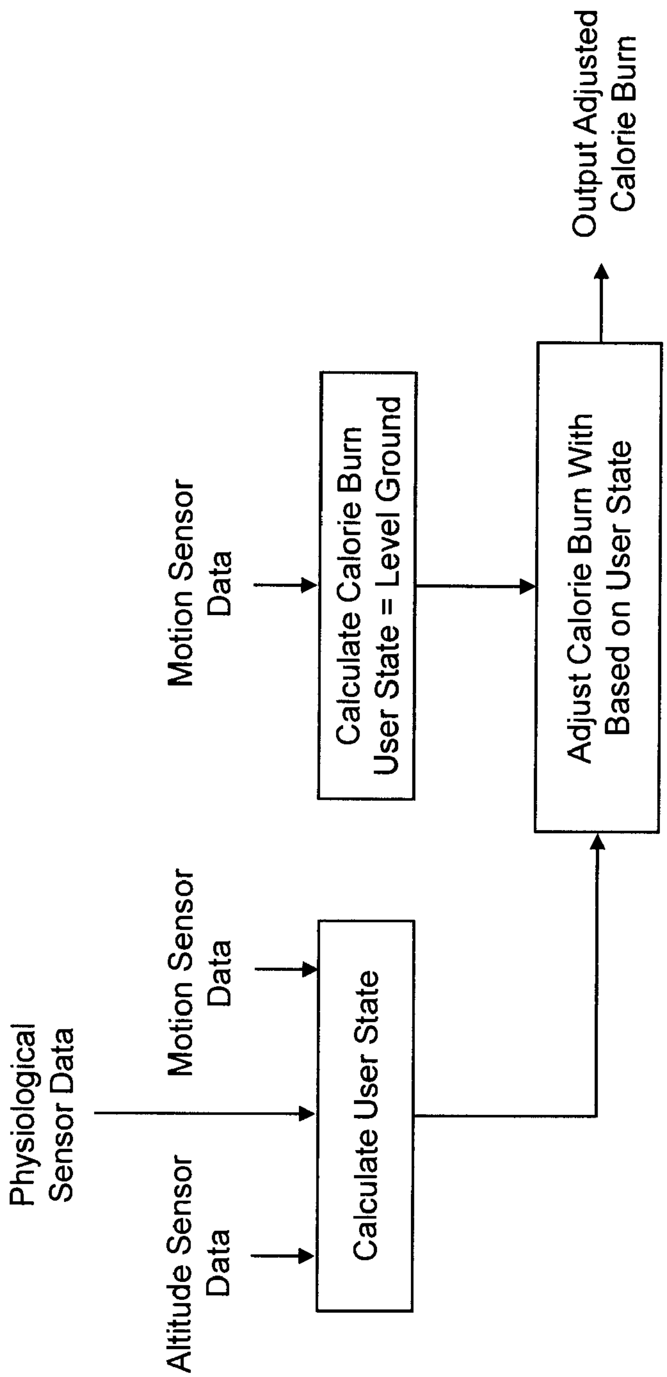

Altitude Sensor Data
Physiological Sensor Data
Motion Sensor Data
Calculate User State
Motion Sensor Data
Calculate Calorie Burn User State = Level Ground
Adjust Calorie Burn With Based on User State
Output Adjusted Calorie Burn

FIGURE 4F

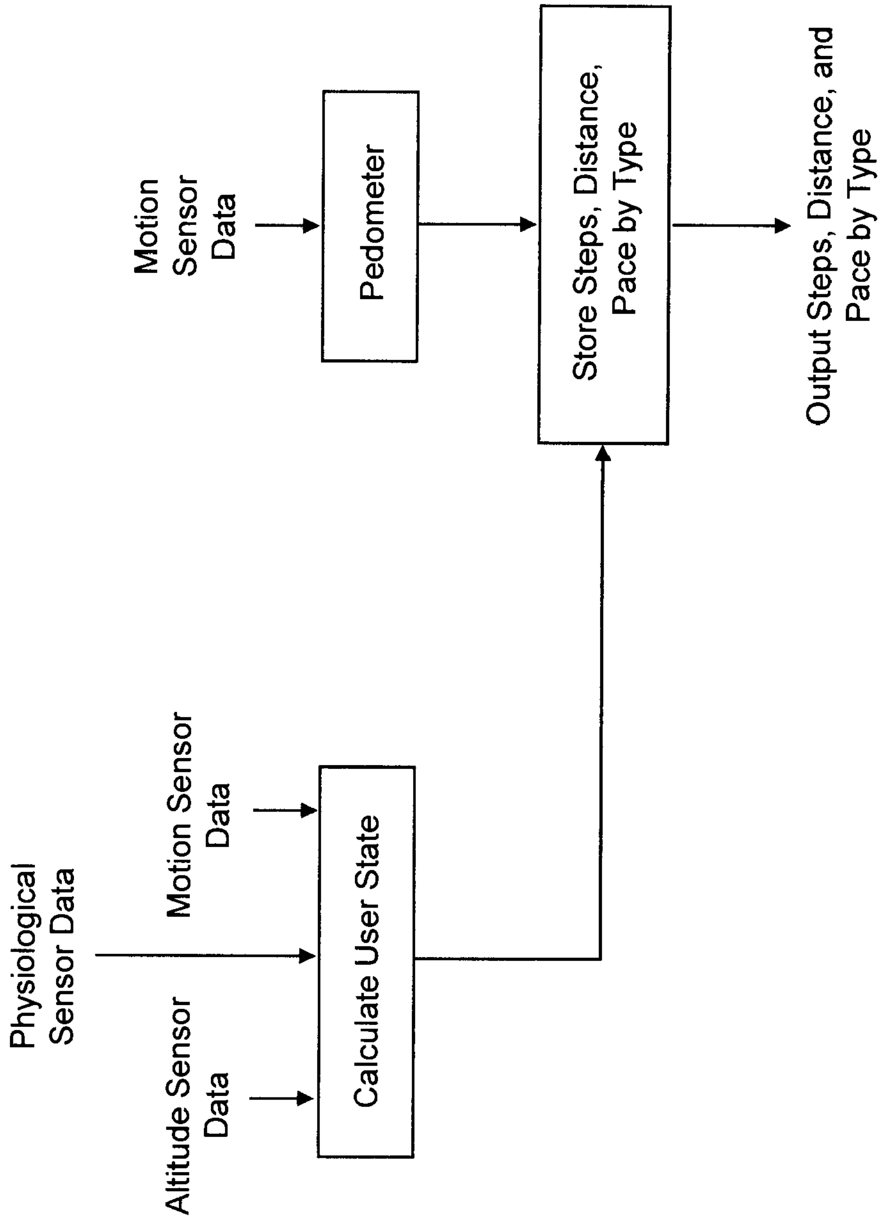

Motion Sensor Data
Pedometer
Store Steps, Distance, Pace by Type
Output Steps, Distance, and Pace by Type
Altitude Sensor Data
Physiological Sensor Data
Motion Sensor Data
Calculate User State

FIGURE 4G

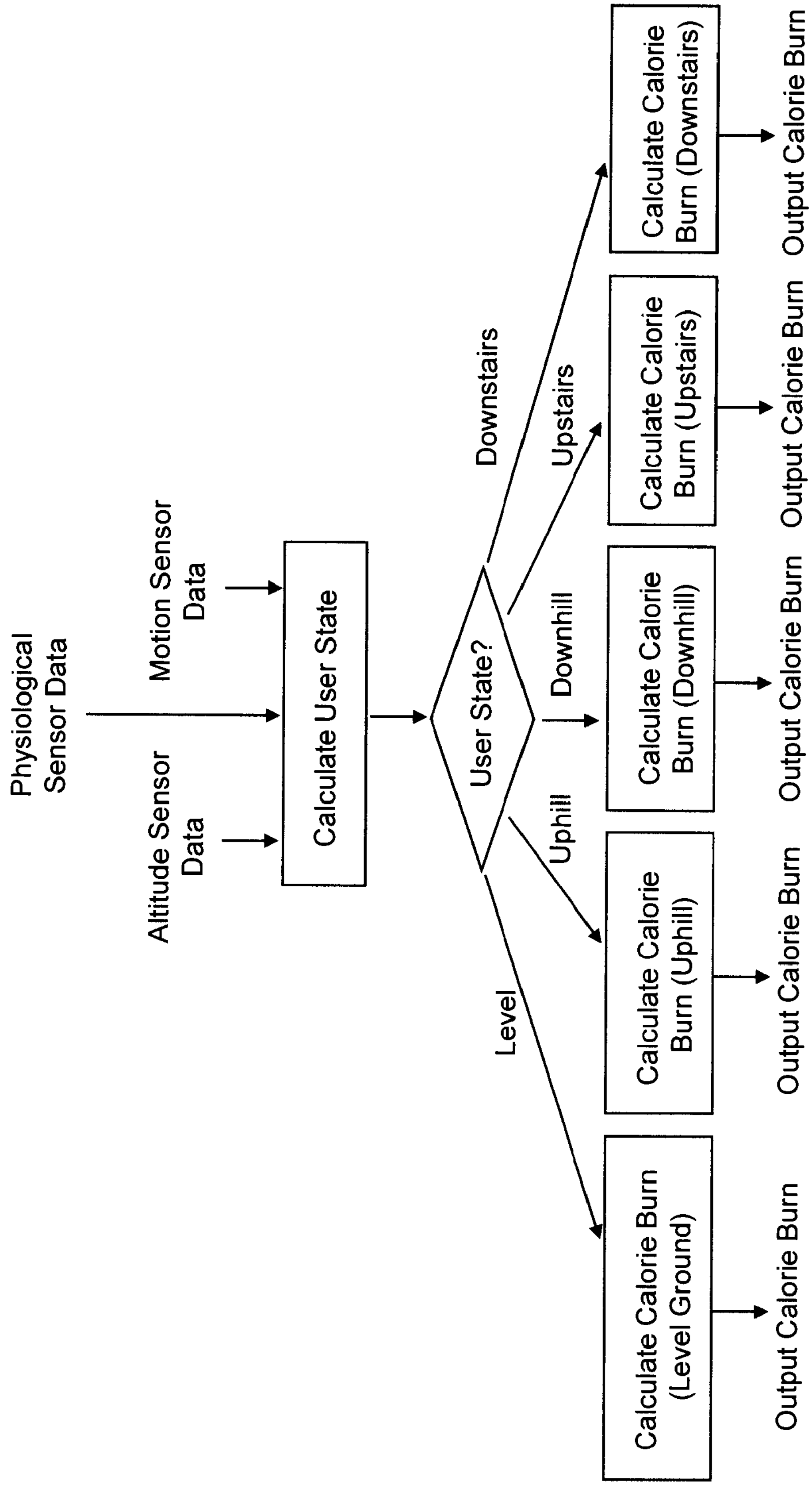

Physiological Sensor Data
Altitude Sensor Data
Motion Sensor Data
Calculate User State
User State?
Level
Uphill
Downhill
Upstairs
Downstairs
Calculate Calorie Burn (Level Ground)
Calculate Calorie Burn (Uphill)
Calculate Calorie Burn (Downhill)
Calculate Calorie Burn (Upstairs)
Calculate Calorie Burn (Downstairs)
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn

FIGURE 4H

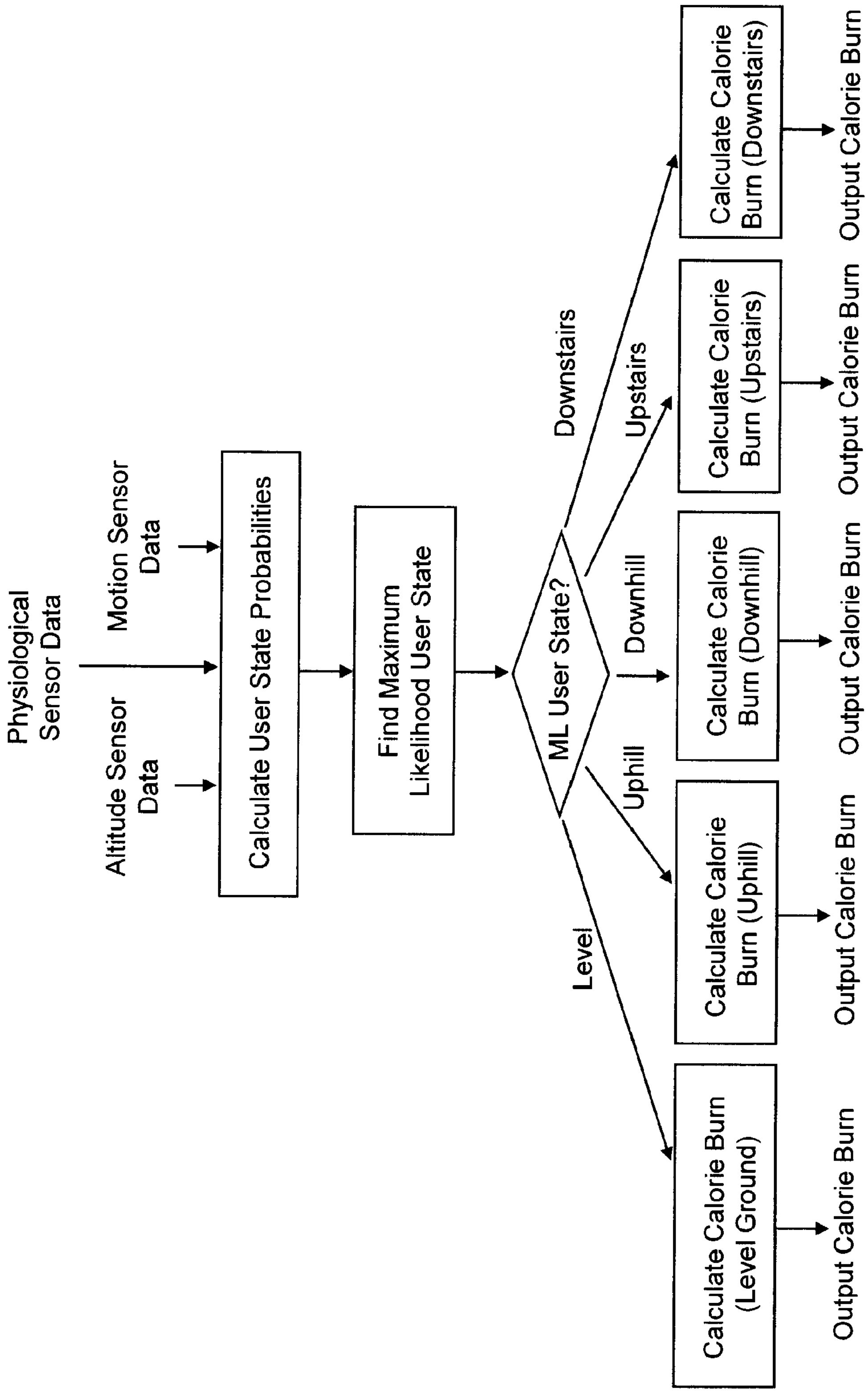

Altitude Sensor Data
Physiological Sensor Data
Motion Sensor Data
Calculate User State Probabilities
Find Maximum Likelihood User State
ML User State?
Level
Uphill
Downhill
Upstairs
Downstairs
Calculate Calorie Burn (Level Ground)
Calculate Calorie Burn (Uphill)
Calculate Calorie Burn (Downhill)
Calculate Calorie Burn (Upstairs)
Calculate Calorie Burn (Downstairs)
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn

FIGURE 4I

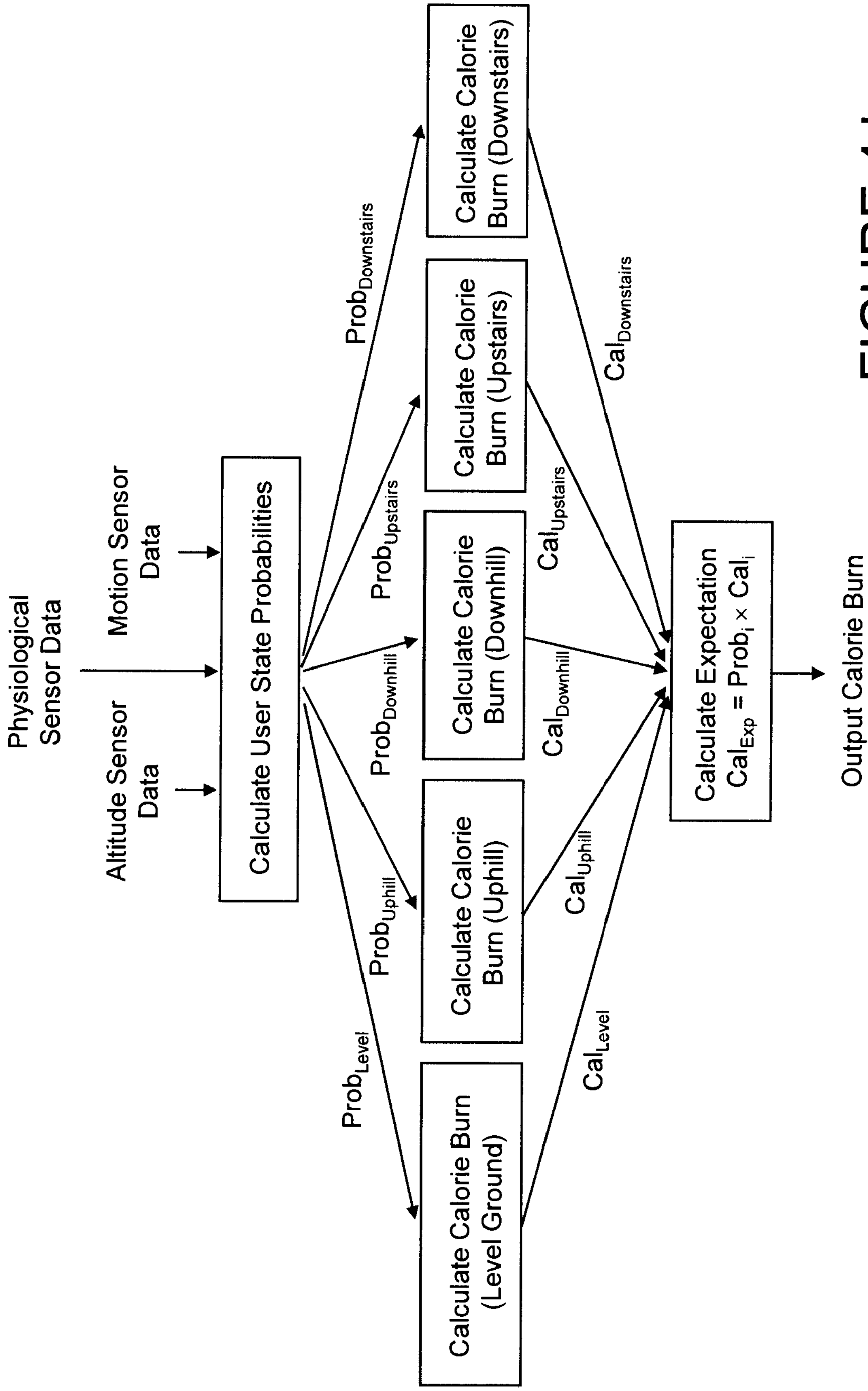

Physiological Sensor Data
Motion Sensor Data
Altitude Sensor Data
Calculate User State Probabilities
$Prob_{Downstairs}$
$Prob_{Upstairs}$
$Prob_{Downhill}$
$Prob_{Uphill}$
$Prob_{Level}$
Calculate Calorie Burn (Downstairs)
Calculate Calorie Burn (Upstairs)
Calculate Calorie Burn (Downhill)
Calculate Calorie Burn (Uphill)
Calculate Calorie Burn (Level Ground)
$Cal_{Downstairs}$
$Cal_{Upstairs}$
$Cal_{Downhill}$
Cal_{Uphill}
Cal_{Level}
Calculate Expectation $Cal_{Exp} = Prob_i \times Cal_i$
Output Calorie Burn

FIGURE 4J

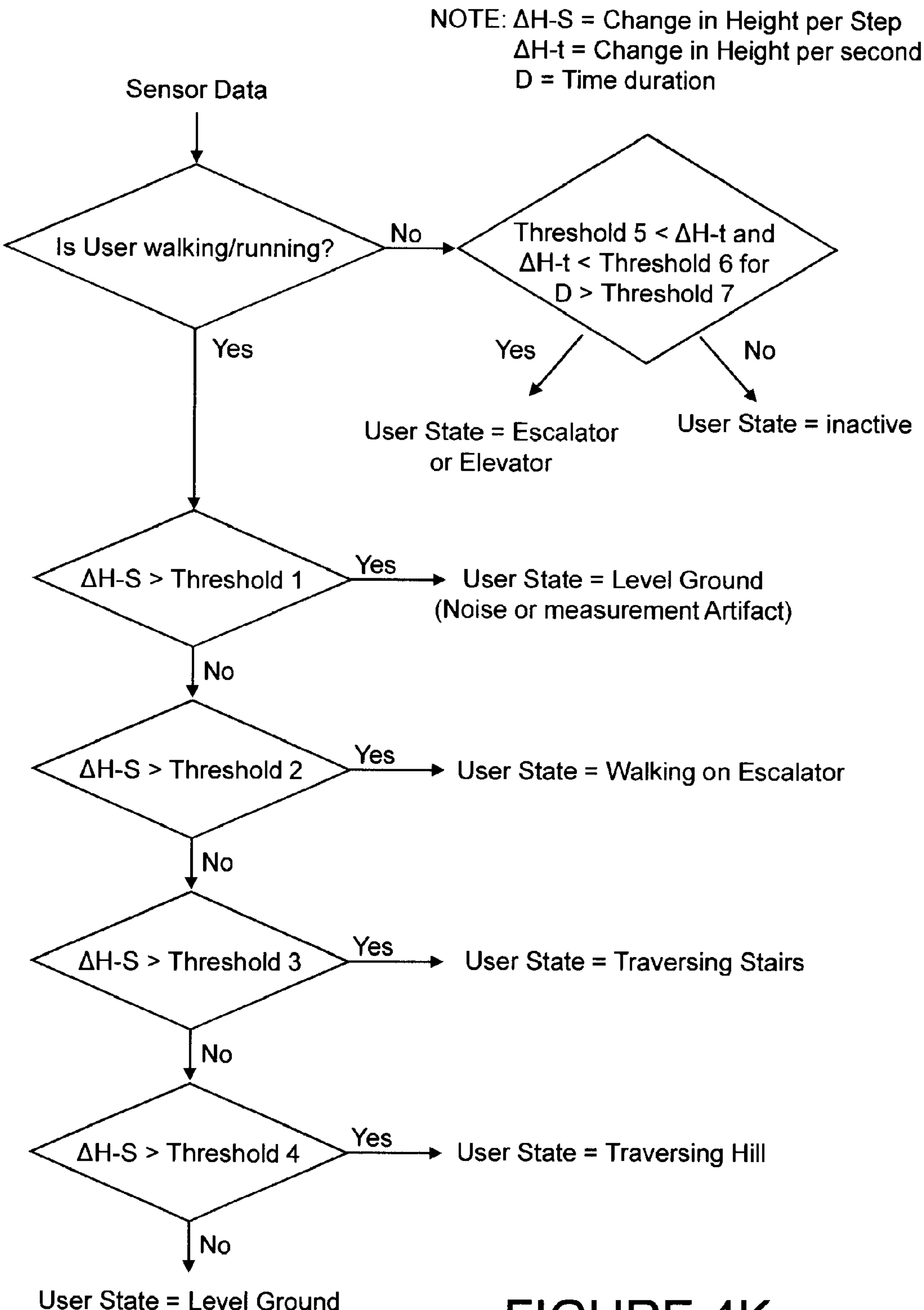

NOTE: ΔH-S = Change in Height per Step
ΔH-t = Change in Height per second
D = Time duration
Sensor Data
Is User walking/running?
No
Threshold 5 < ΔH-t and ΔH-t < Threshold 6 for D > Threshold 7
Yes
No
User State = Escalator or Elevator
User State = inactive
Yes
ΔH-S > Threshold 1
Yes
User State = Level Ground (Noise or measurement Artifact)
No
ΔH-S > Threshold 2
Yes
User State = Walking on Escalator
No
ΔH-S > Threshold 3
Yes
User State = Traversing Stairs
No
ΔH-S > Threshold 4
Yes
User State = Traversing Hill
No
User State = Level Ground

FIGURE 4K

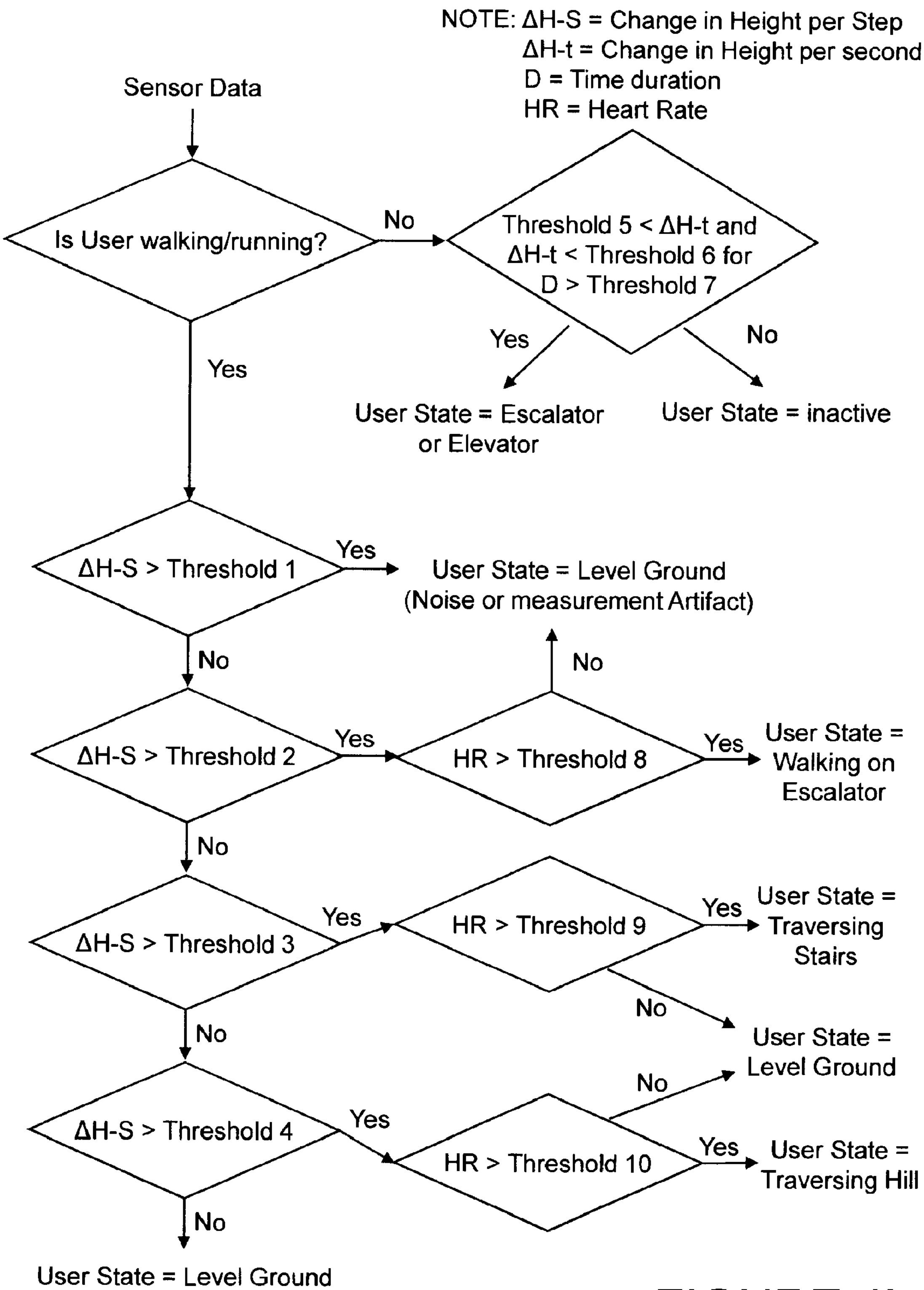

NOTE: ΔH-S = Change in Height per Step
ΔH-t = Change in Height per second
D = Time duration
HR = Heart Rate
Sensor Data
Is User walking/running?
No
Threshold 5 < ΔH-t and ΔH-t < Threshold 6 for D > Threshold 7
Yes
No
User State = Escalator or Elevator
User State = inactive
Yes
ΔH-S > Threshold 1
Yes
User State = Level Ground (Noise or measurement Artifact)
No
No
ΔH-S > Threshold 2
Yes
HR > Threshold 8
Yes
User State = Walking on Escalator
No
ΔH-S > Threshold 3
Yes
HR > Threshold 9
Yes
User State = Traversing Stairs
No
User State = Level Ground
No
ΔH-S > Threshold 4
Yes
HR > Threshold 10
No
Yes
User State = Traversing Hill
No
User State = Level Ground

FIGURE 4L

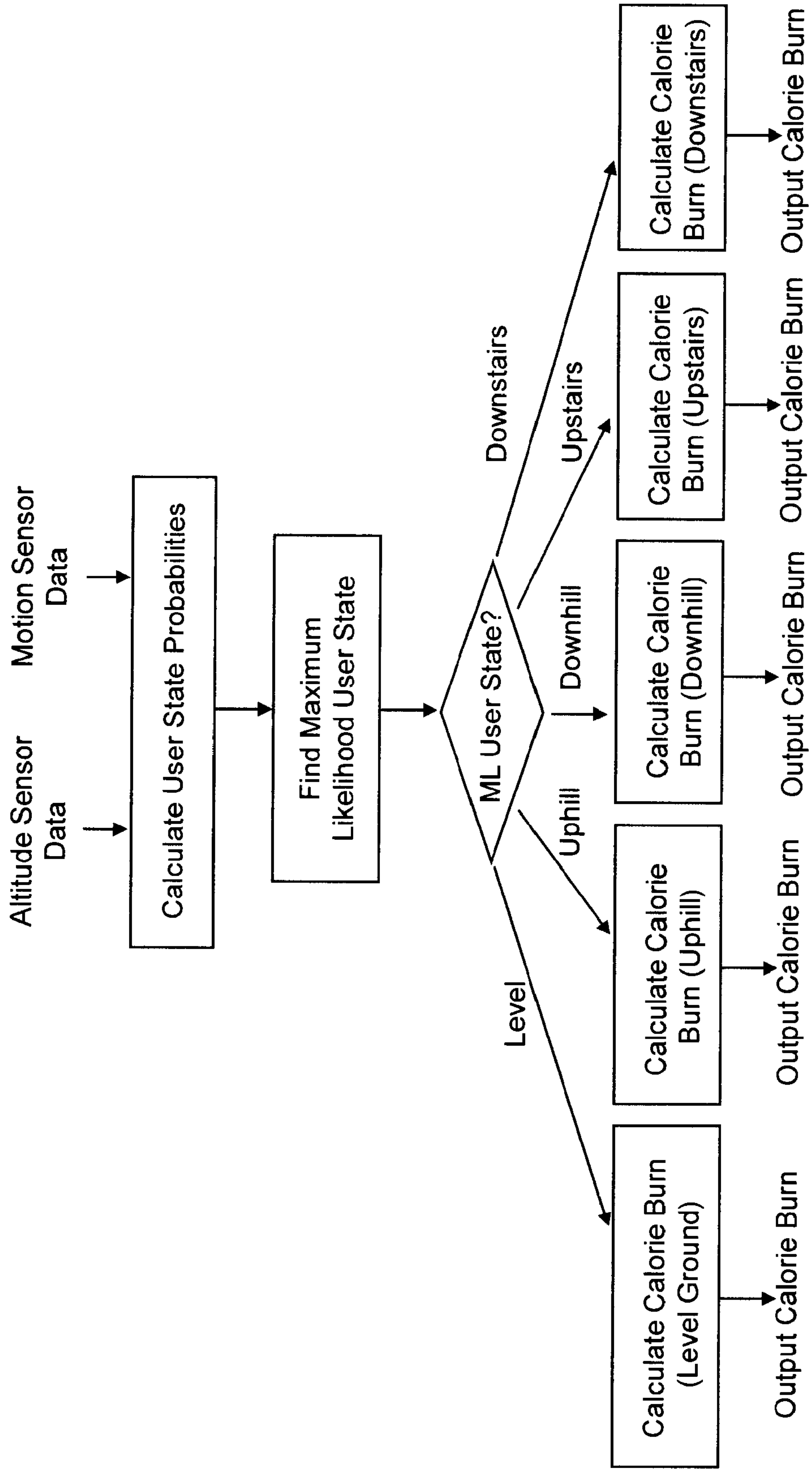

Altitude Sensor Data
Motion Sensor Data
Calculate User State Probabilities
Find Maximum Likelihood User State
ML User State?
Level
Uphill
Downhill
Upstairs
Downstairs
Calculate Calorie Burn (Level Ground)
Calculate Calorie Burn (Uphill)
Calculate Calorie Burn (Downhill)
Calculate Calorie Burn (Upstairs)
Calculate Calorie Burn (Downstairs)
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn

FIGURE 4M

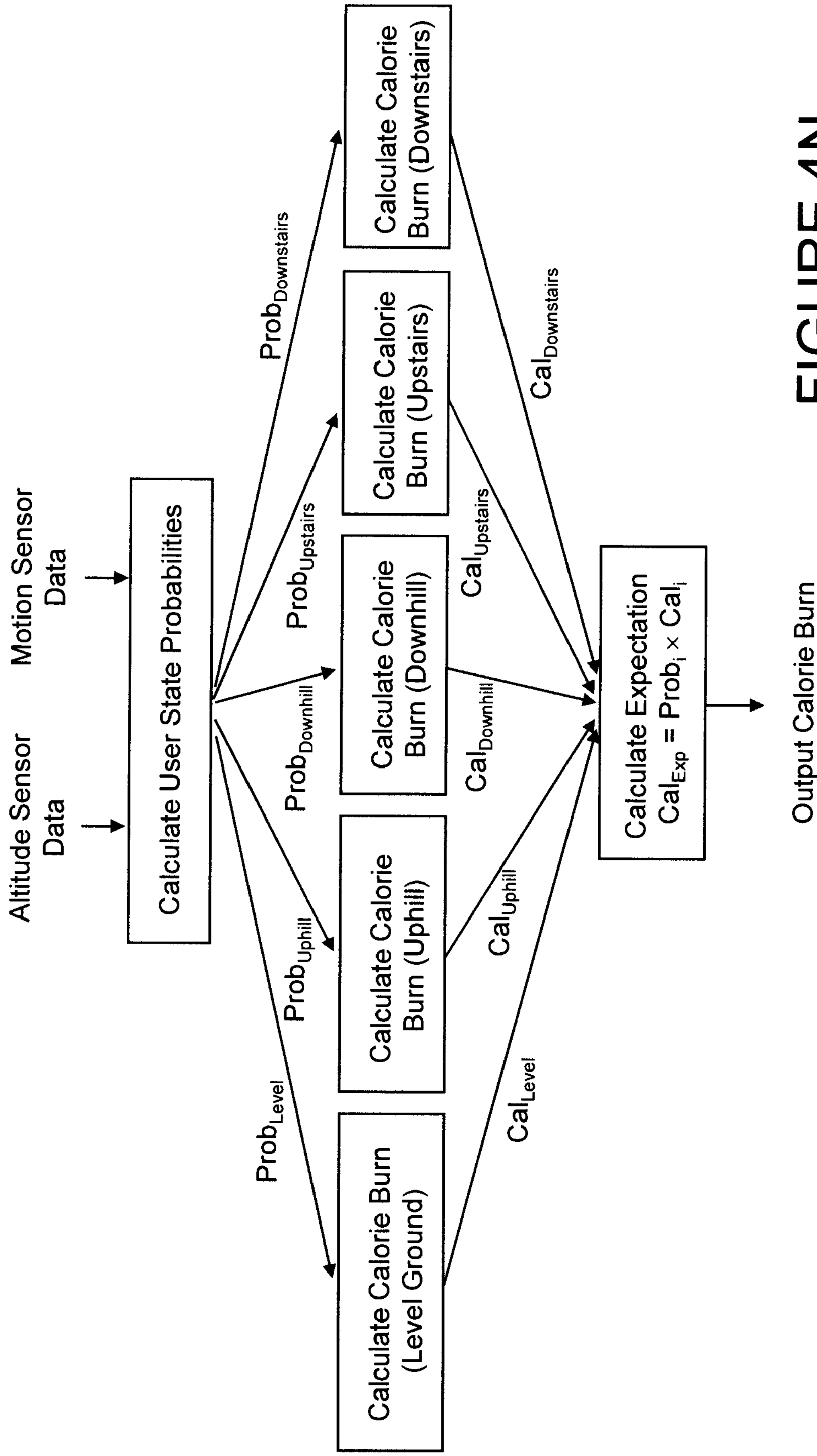

Altitude Sensor Data
Motion Sensor Data
Calculate User State Probabilities
$Prob_{Level}$
$Prob_{Uphill}$
$Prob_{Downhill}$
$Prob_{Upstairs}$
$Prob_{Downstairs}$
Calculate Calorie Burn (Level Ground)
Calculate Calorie Burn (Uphill)
Calculate Calorie Burn (Downhill)
Calculate Calorie Burn (Upstairs)
Calculate Calorie Burn (Downstairs)
Cal_{Level}
Cal_{Uphill}
$Cal_{Downhill}$
$Cal_{Upstairs}$
$Cal_{Downstairs}$
Calculate Expectation $Cal_{Exp} = Prob_i \times Cal_i$
Output Calorie Burn

FIGURE 4N

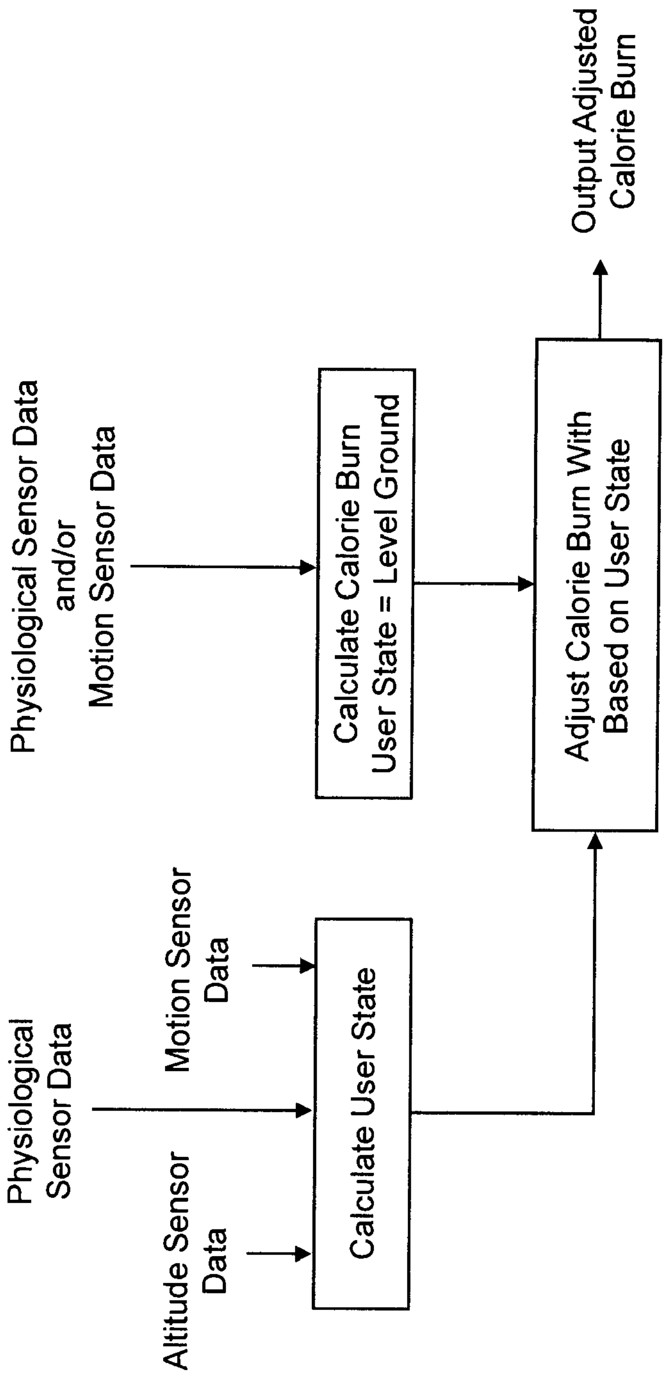

Physiological Sensor Data
and/or
Motion Sensor Data
Calculate Calorie Burn
User State = Level Ground
Adjust Calorie Burn With
Based on User State
Output Adjusted
Calorie Burn
Physiological
Sensor Data
Motion Sensor
Data
Altitude Sensor
Data
Calculate User State

FIGURE 4O

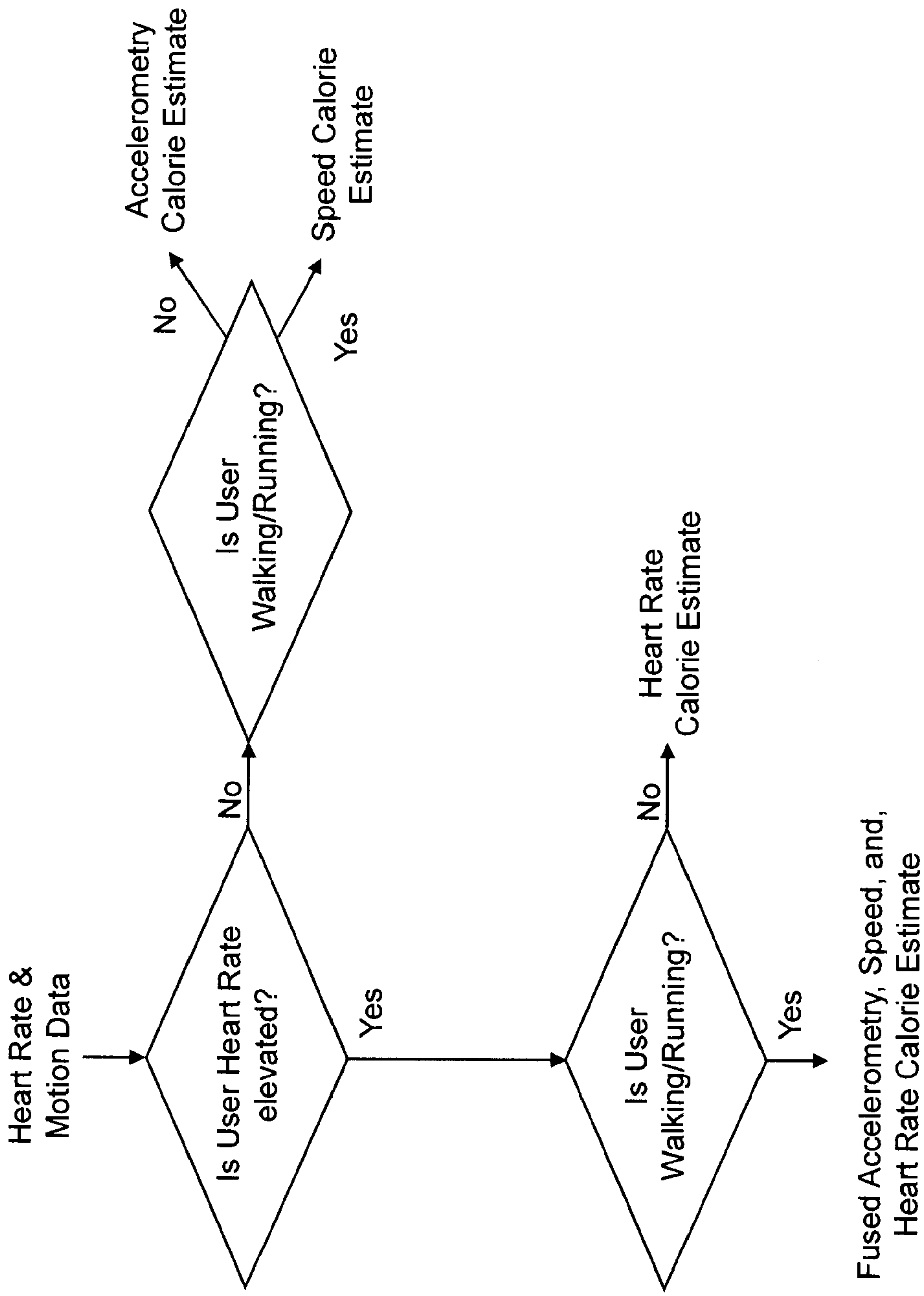

Heart Rate & Motion Data
Is User Heart Rate elevated?
No
Yes
Is User Walking/Running?
No
Yes
Accelerometry Calorie Estimate
Speed Calorie Estimate
Is User Walking/Running?
No
Yes
Heart Rate Calorie Estimate
Fused Accelerometry, Speed, and, Heart Rate Calorie Estimate

FIGURE 4P

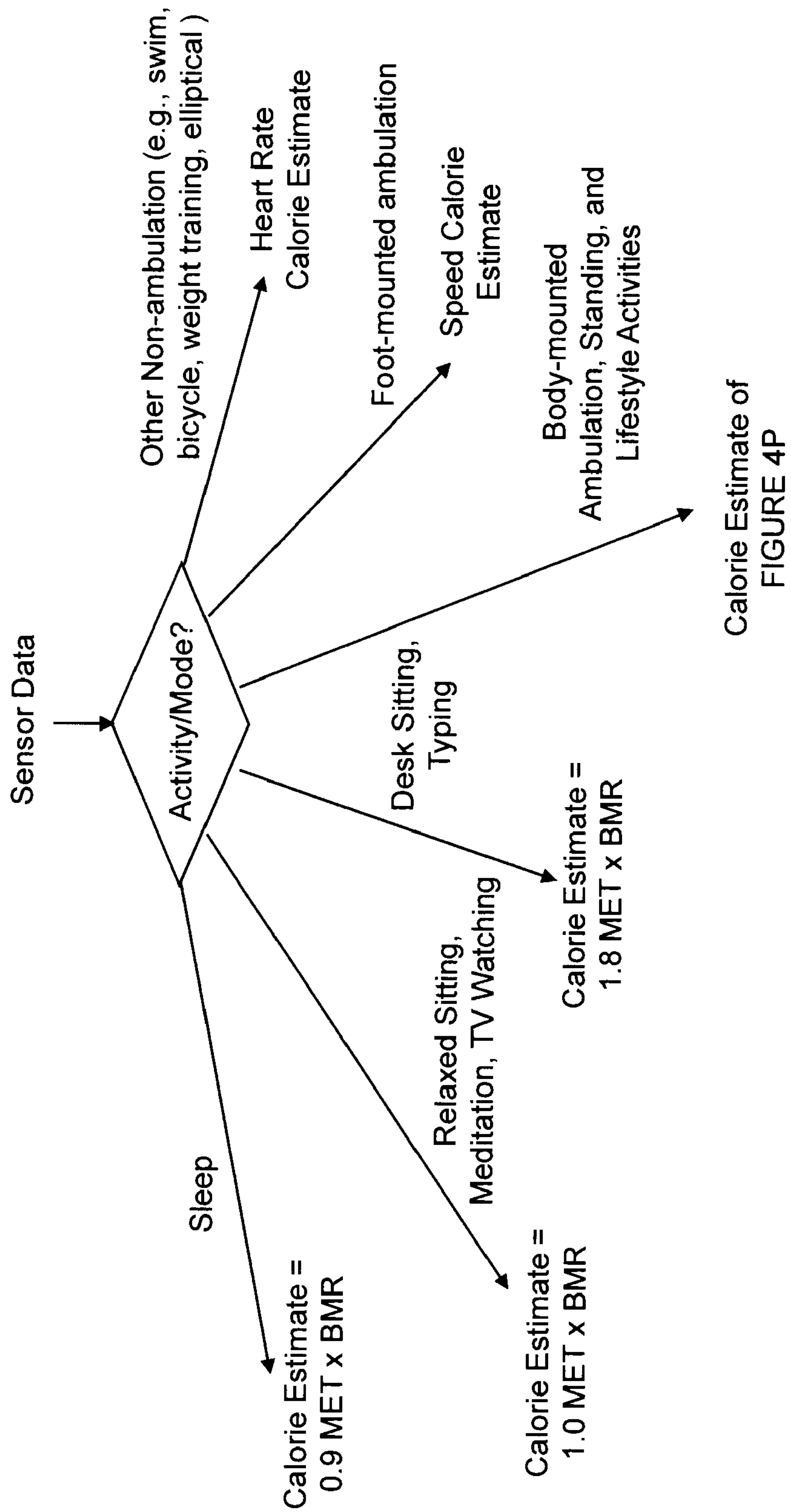

Sensor Data
Activity/Mode?
Other Non-ambulation (e.g., swim, bicycle, weight training, elliptical)
Heart Rate Calorie Estimate
Foot-mounted ambulation
Speed Calorie Estimate
Body-mounted Ambulation, Standing, and Lifestyle Activities
Calorie Estimate of FIGURE 4P
Desk Sitting, Typing
Calorie Estimate = 1.8 MET x BMR
Relaxed Sitting, Meditation, TV Watching
Calorie Estimate = 1.0 MET x BMR
Sleep
Calorie Estimate = 0.9 MET x BMR

FIGURE 4Q

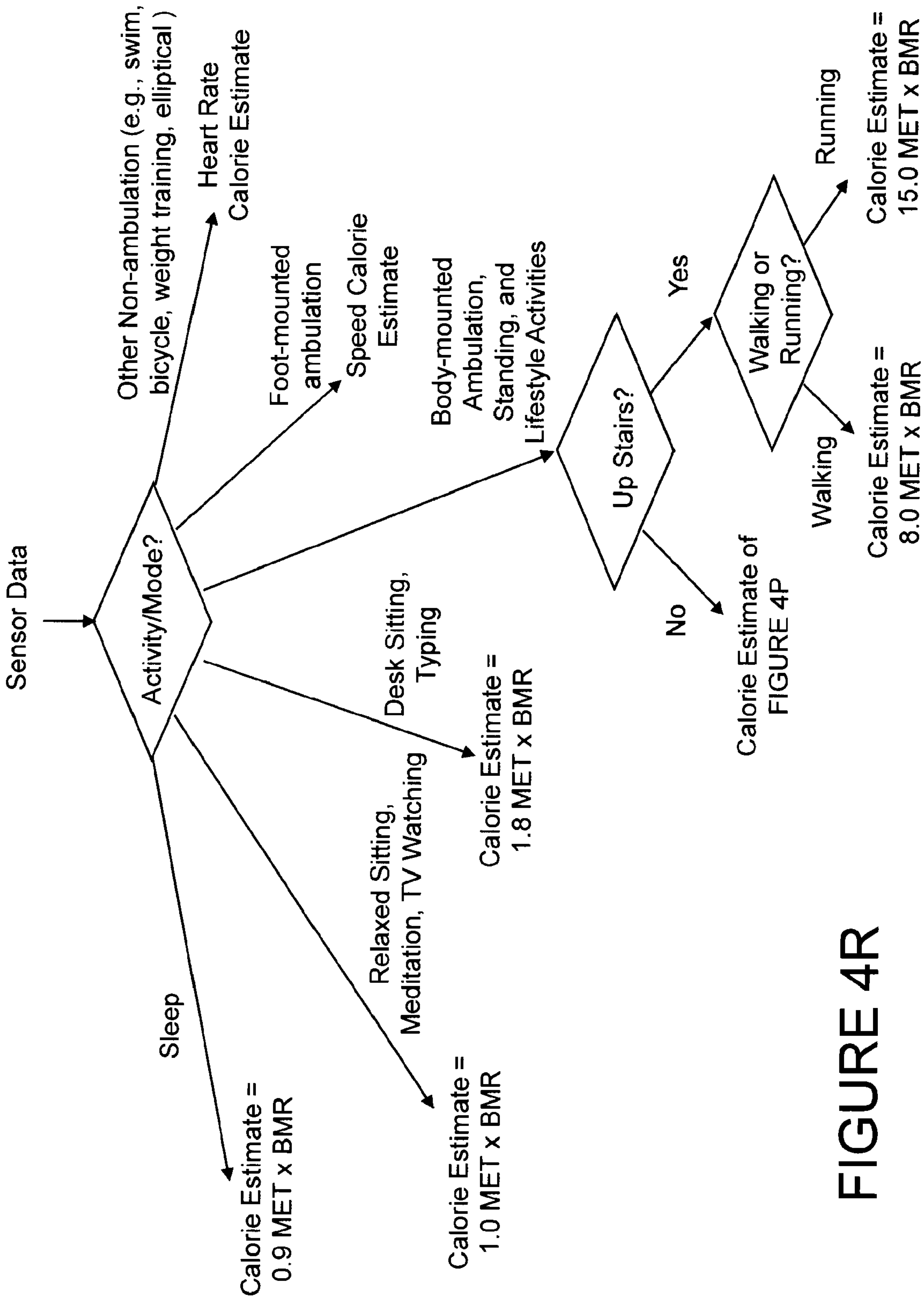

Sensor Data
Activity/Mode?
Other Non-ambulation (e.g., swim, bicycle, weight training, elliptical)
Heart Rate Calorie Estimate
Foot-mounted ambulation
Speed Calorie Estimate
Body-mounted Ambulation, Standing, and Lifestyle Activities
Up Stairs?
Yes
Walking or Running?
Running
Calorie Estimate = 15.0 MET x BMR
Walking
Calorie Estimate = 8.0 MET x BMR
No
Calorie Estimate of FIGURE 4P
Desk Sitting, Typing
Calorie Estimate = 1.8 MET x BMR
Relaxed Sitting, Meditation, TV Watching
Calorie Estimate = 1.0 MET x BMR
Sleep
Calorie Estimate = 0.9 MET x BMR

FIGURE 4R

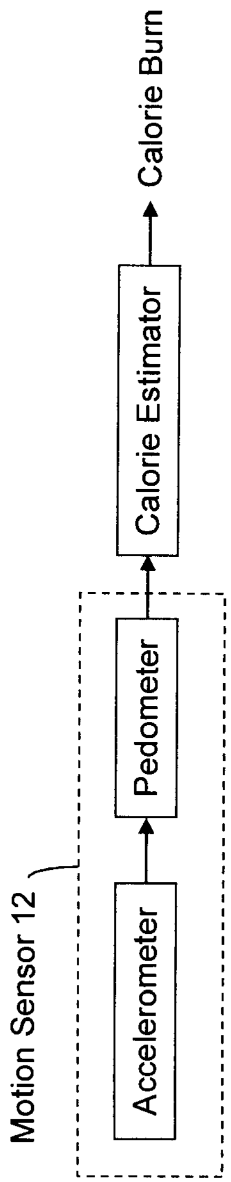


FIGURE 5A

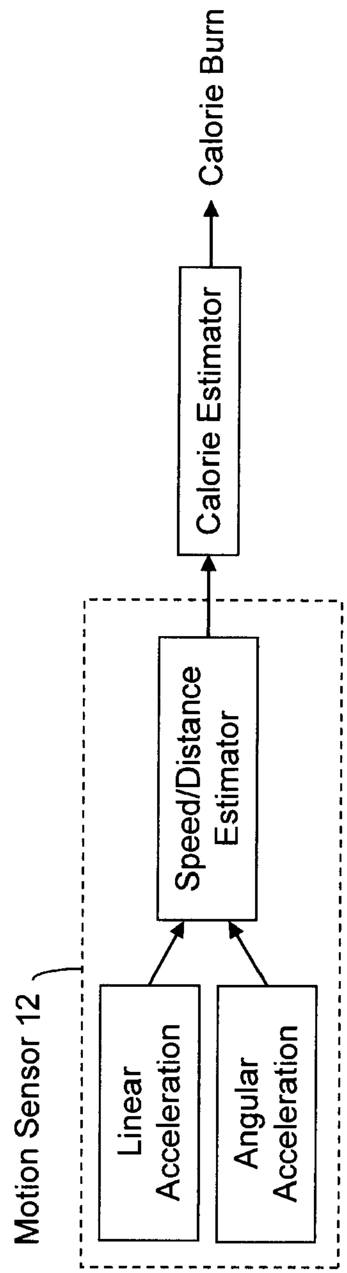


FIGURE 5B

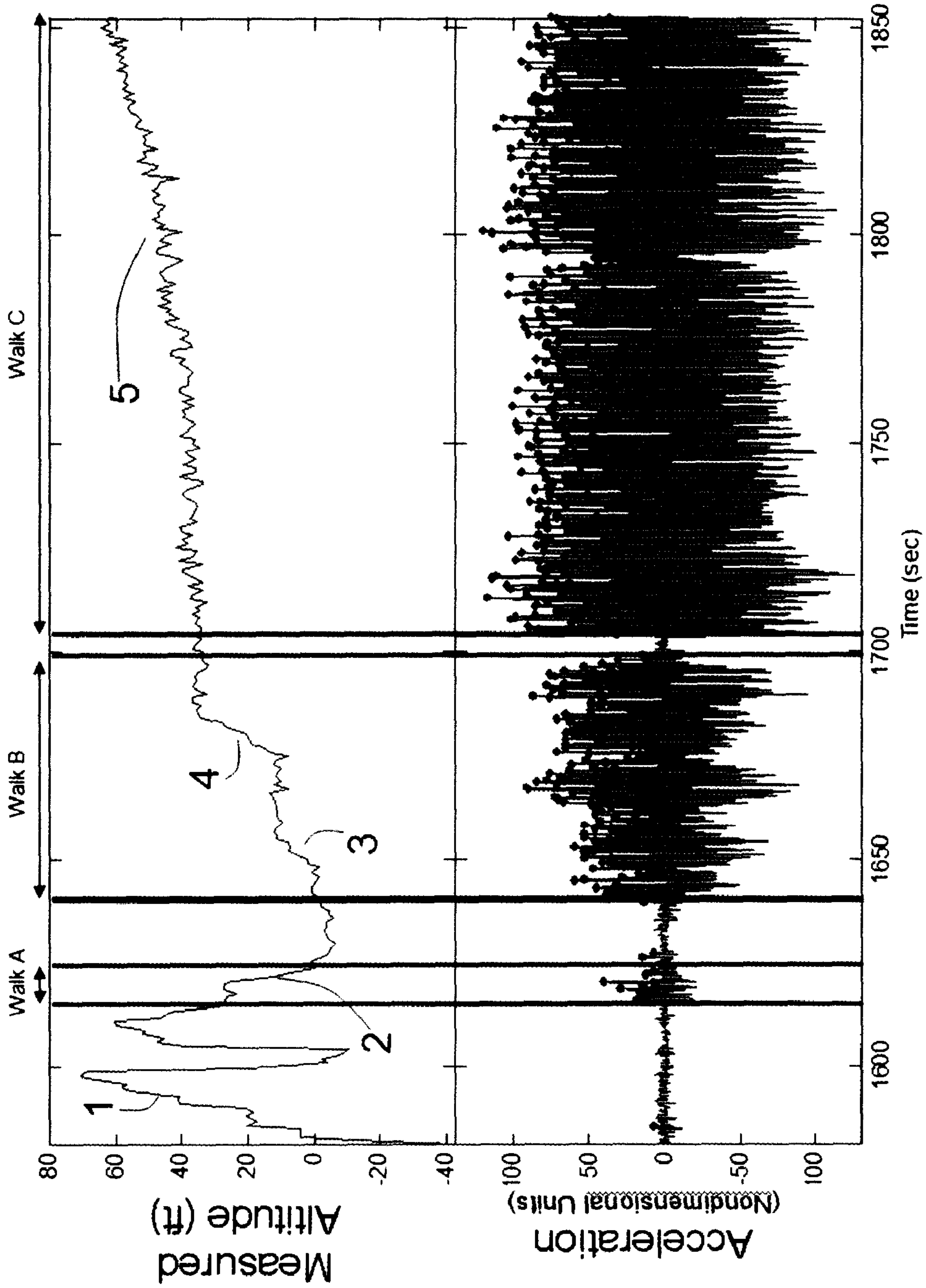

Walk A
Walk B
Walk C
Measured Altitude (ft)
Acceleration (Nondimensional Units)
Time (sec)
1
2
3
4
5
80
60
40
20
0
-20
-40
100
50
0
-50
100
1600
1650
1700
1750
1800
1850

FIGURE 6

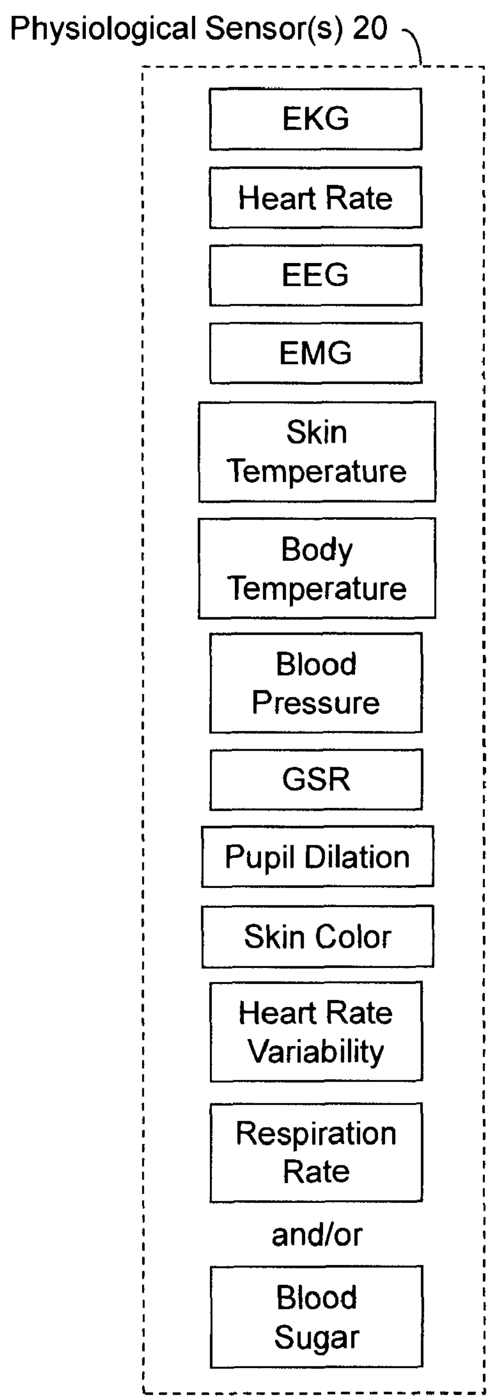

Physiological Sensor(s) 20
EKG
Heart Rate
EEG
EMG
Skin Temperature
Body Temperature
Blood Pressure
GSR
Pupil Dilation
Skin Color
Heart Rate Variability
Respiration Rate
and/or
Blood Sugar

FIGURE 7

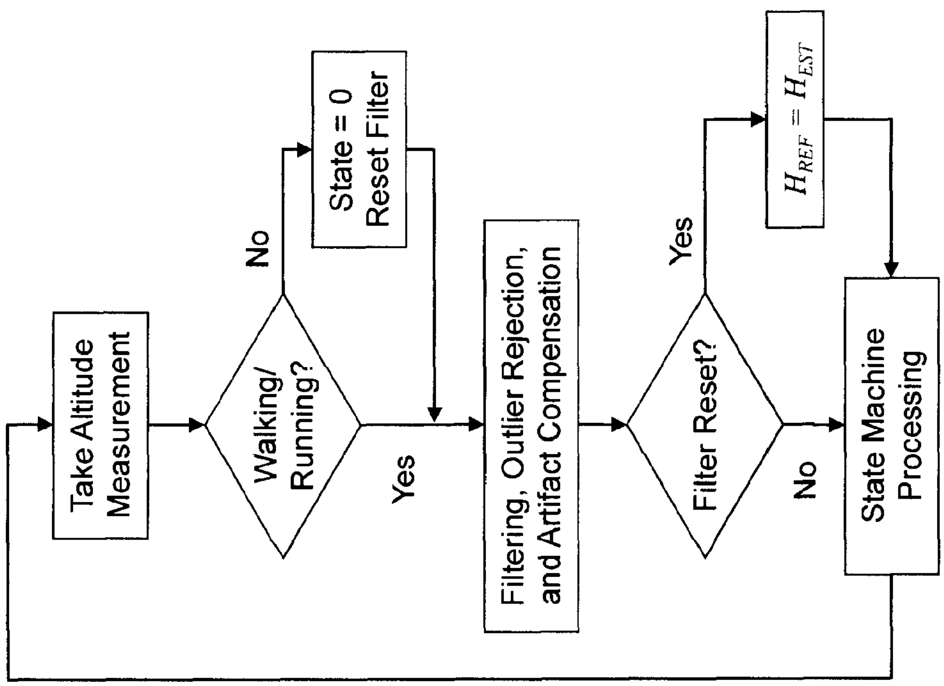


FIGURE 8A

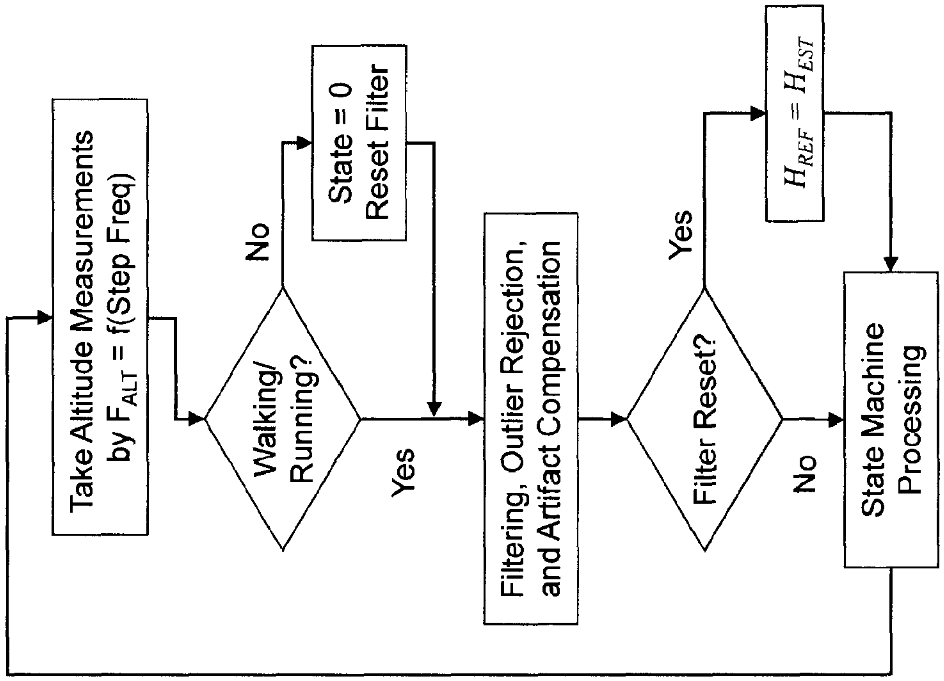
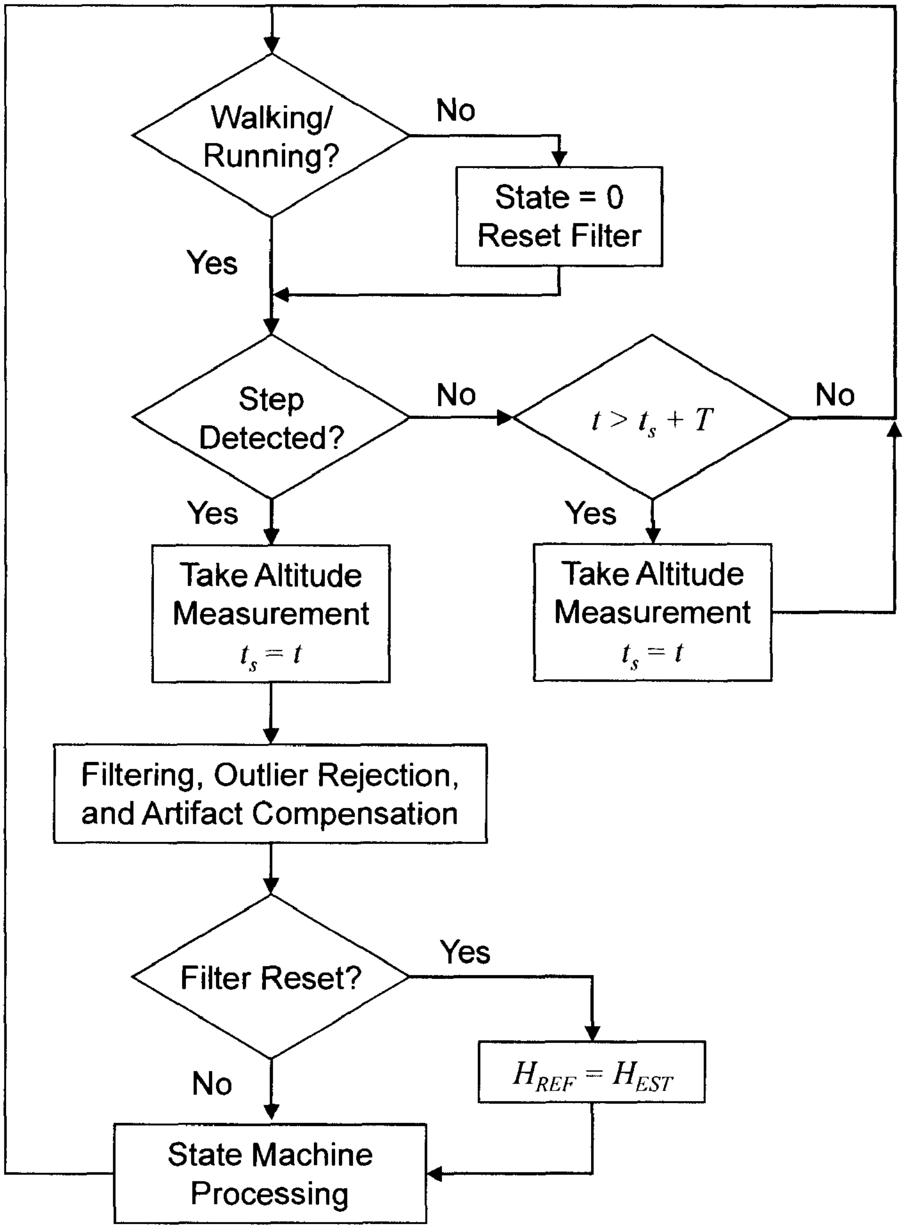


FIGURE 8B



Walking/ Running?
No
State = 0
Reset Filter
Yes
Step Detected?
No
$t > t_s + T$
No
Yes
Yes
Take Altitude Measurement
$t_s = t$
Take Altitude Measurement
$t_s = t$
Filtering, Outlier Rejection, and Artifact Compensation
Filter Reset?
Yes
$H_{REF} = H_{EST}$
No
State Machine Processing

FIGURE 8C

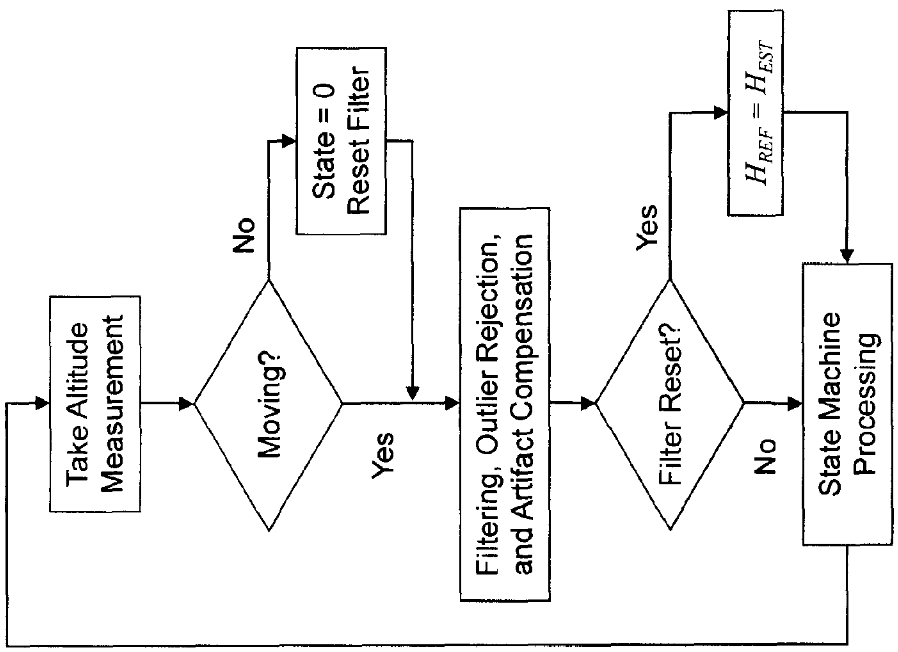


FIGURE 8D

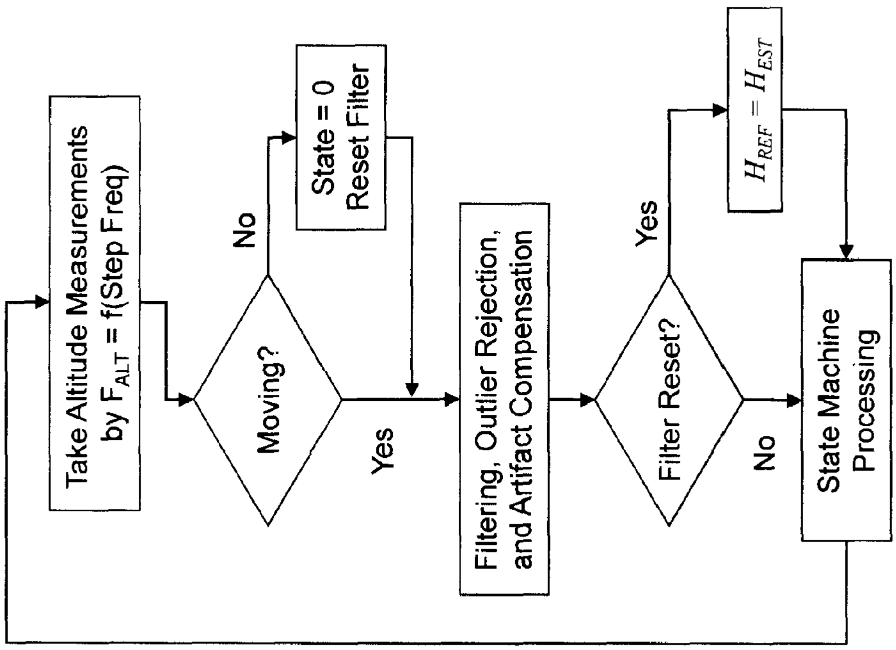


FIGURE 8E

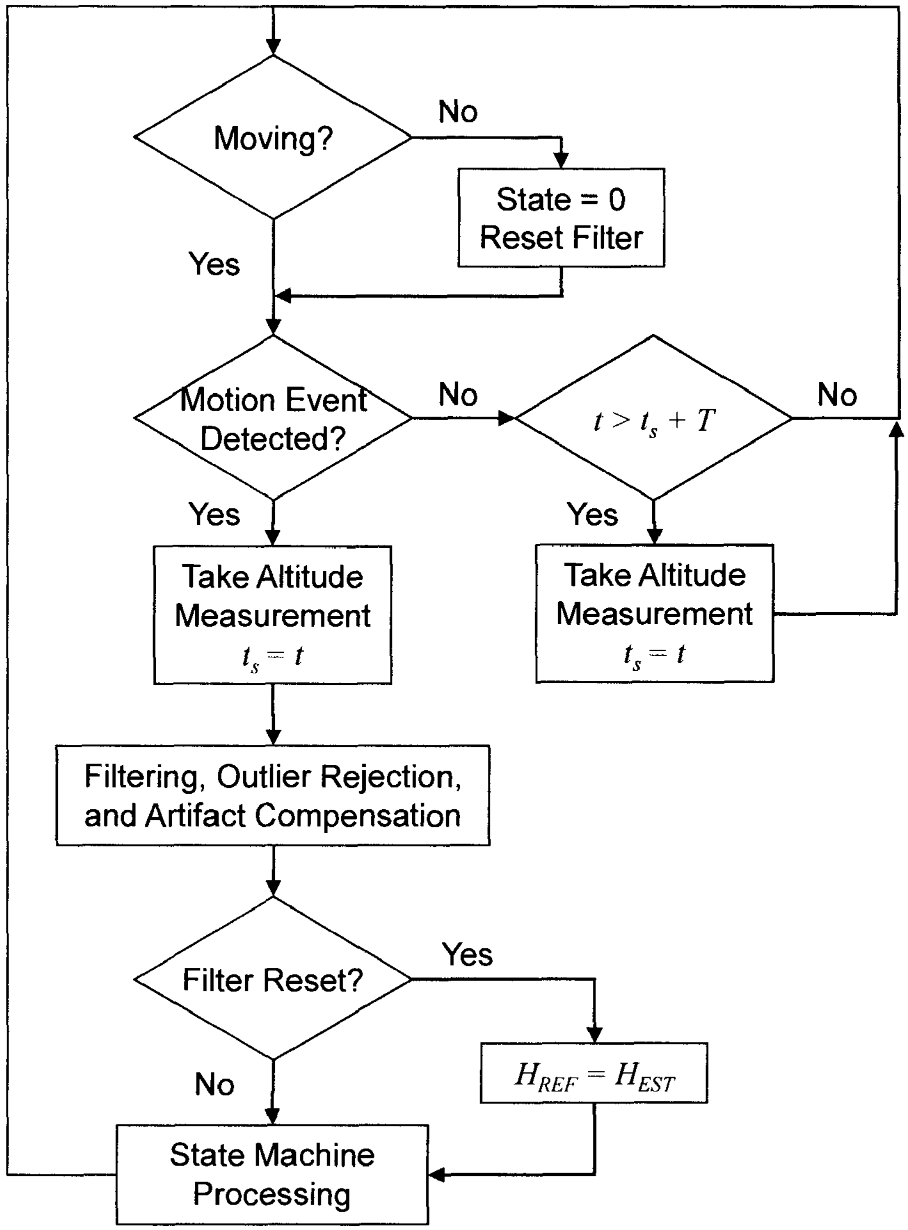
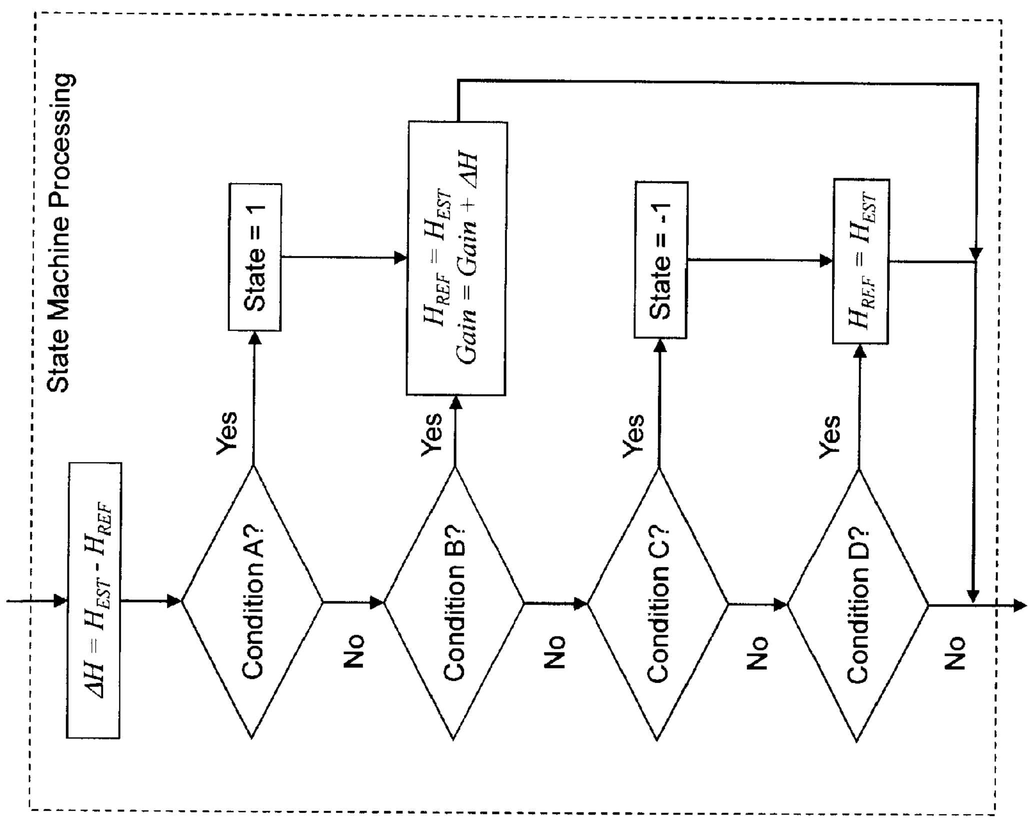

Moving?
No
State = 0
Reset Filter
Yes
Motion Event Detected?
No
$t > t_s + T$
No
Yes
Take Altitude Measurement
$t_s = t$
Yes
Take Altitude Measurement
$t_s = t$
Filtering, Outlier Rejection, and Artifact Compensation
Filter Reset?
Yes
$H_{REF} = H_{EST}$
No
State Machine Processing

FIGURE 8F



Condition	Logical Equivalent
A	State $\leq$ 0 && ΔH > T_{A1} && T_{A2}>ΔH-S>T_{A3} && T_{A4}>ΔH-S>T_{A5}
B	State == 1 && ΔH > T_{B1} && T_{B2}>ΔH-S >T_{B3} && T_{B4}>ΔH-S >T_{B5}
C	State $\geq$ 0 && ΔH > T_{C1} && T_{C2}>ΔH-S >T_{C3} && T_{C4}>ΔH-S>T_{C5}
D	State == -1 && ΔH > T_{D1} && T_{D2}>ΔH-S>T_{D3} && T_{D4}>ΔH-S>T_{D5}

FIGURE 8G

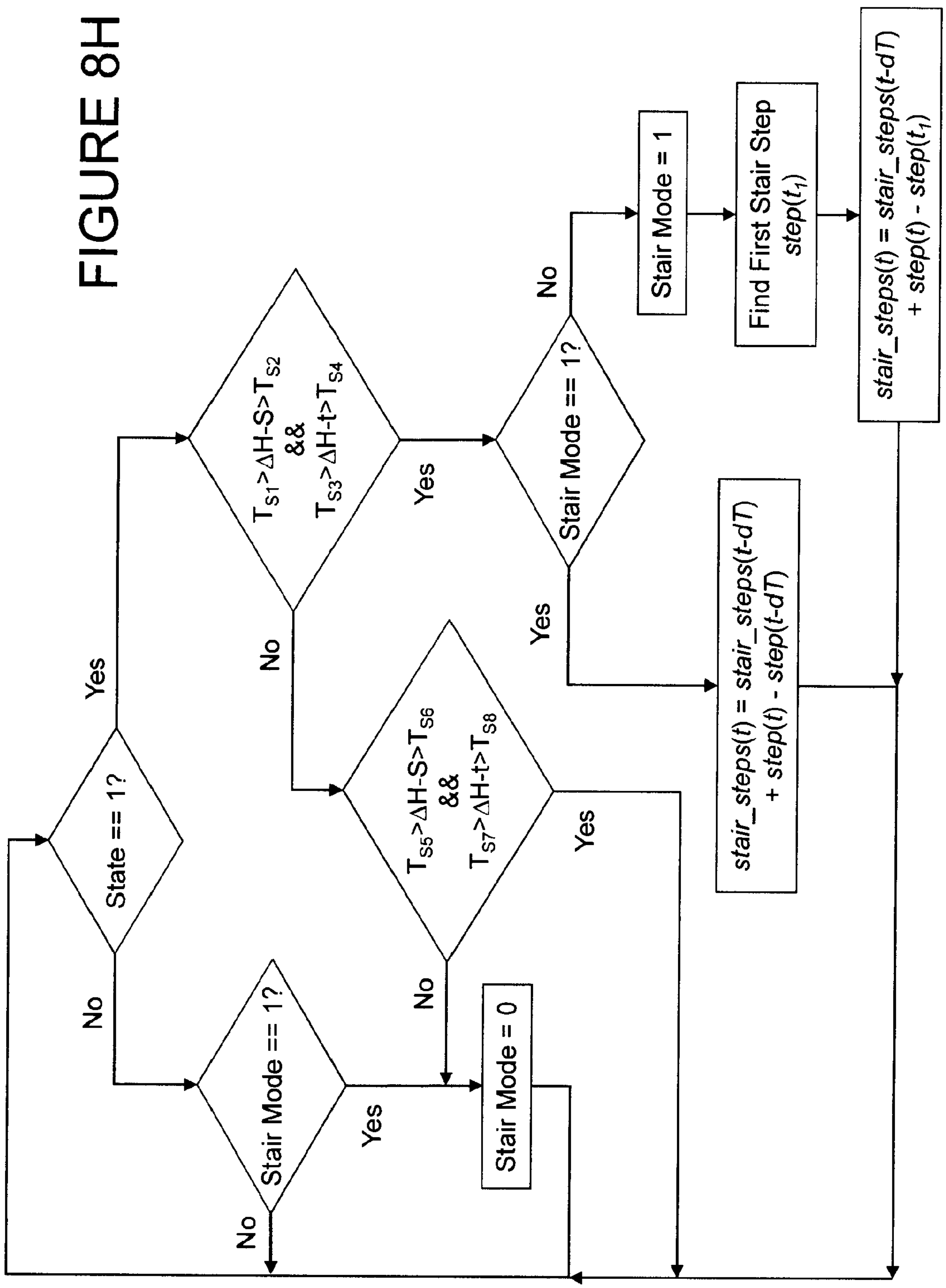

State == 1?
Yes
No
T_{S1}>ΔH-S>T_{S2} && T_{S3}>ΔH-t>T_{S4}
Stair Mode == 1?
T_{S5}>ΔH-S>T_{S6} && T_{S7}>ΔH-t>T_{S8}
Stair Mode = 1
Find First Stair Step
step(t_1)
stair_steps(t) = stair_steps(t-dT) + step(t) - step(t_1)
stair_steps(t) = stair_steps(t-dT) + step(t) - step(t-dT)
Stair Mode = 0

FIGURE 8H

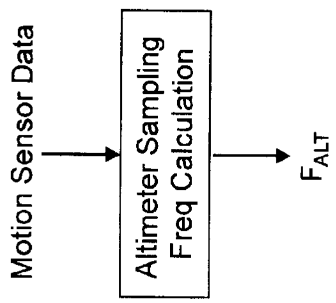


FIGURE 9A

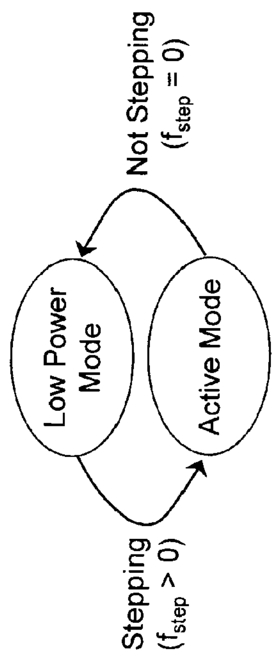


FIGURE 9B

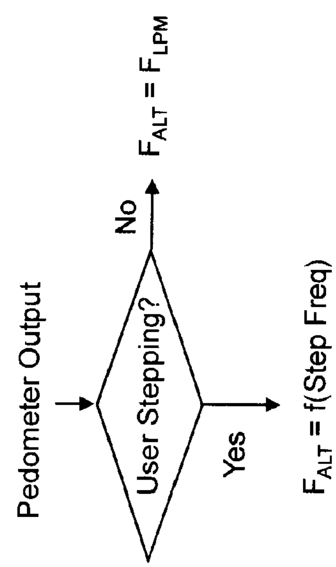


FIGURE 9C

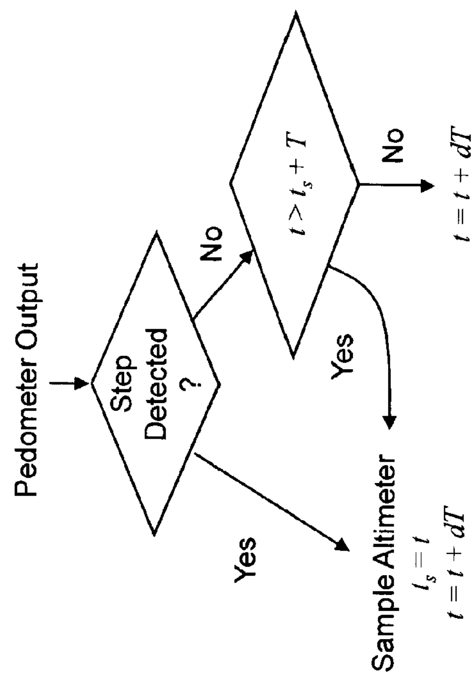


FIGURE 9D

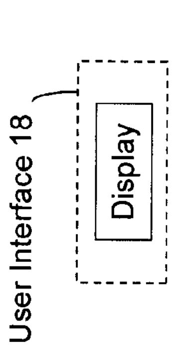


FIGURE 10A

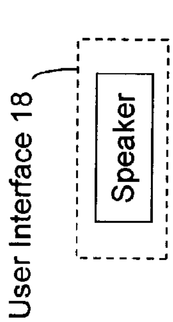


FIGURE 10B

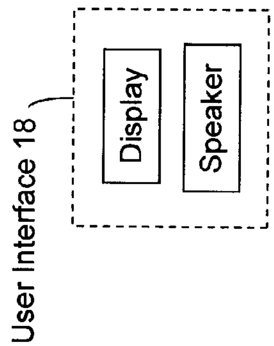


FIGURE 10C

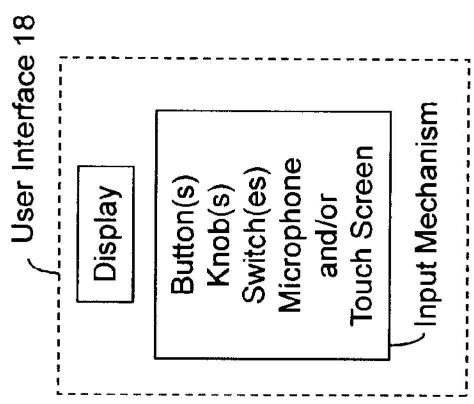


FIGURE 10D

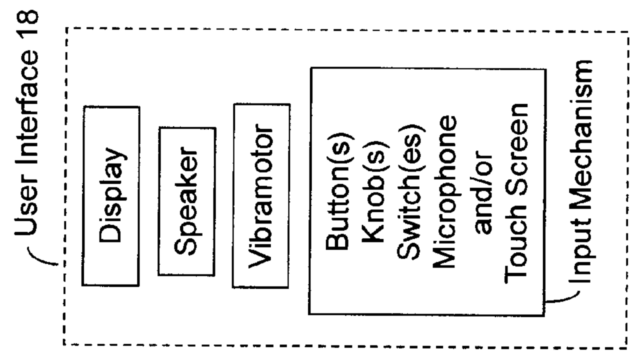


FIGURE 10E

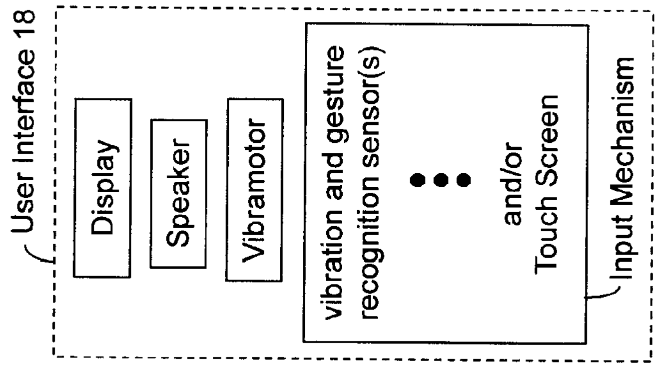


FIGURE 10F

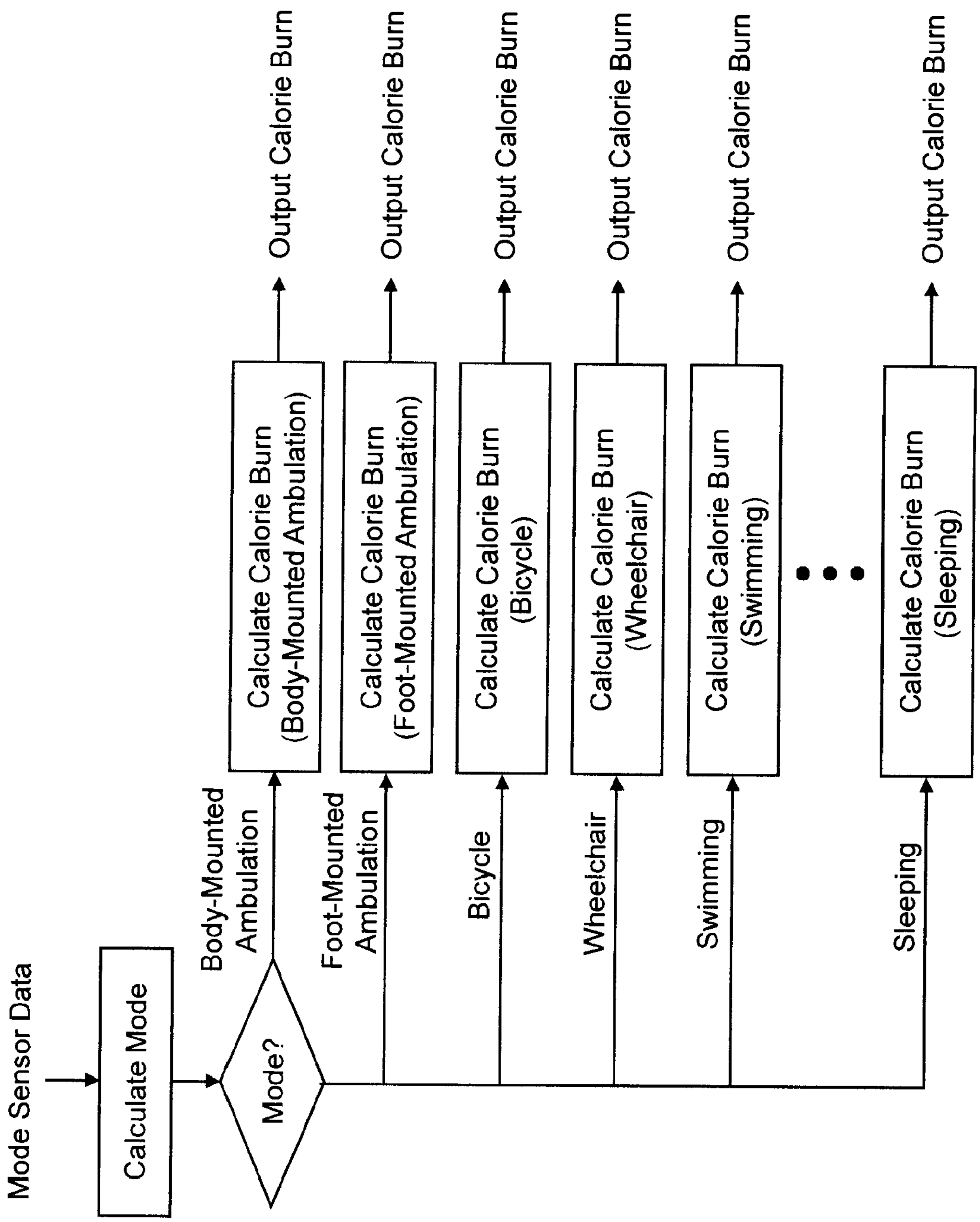

Mode Sensor Data
Calculate Mode
Mode?
Body-Mounted Ambulation
Foot-Mounted Ambulation
Bicycle
Wheelchair
Swimming
Sleeping
Calculate Calorie Burn (Body-Mounted Ambulation)
Calculate Calorie Burn (Foot-Mounted Ambulation)
Calculate Calorie Burn (Bicycle)
Calculate Calorie Burn (Wheelchair)
Calculate Calorie Burn (Swimming)
Calculate Calorie Burn (Sleeping)
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn
Output Calorie Burn

FIGURE 11A

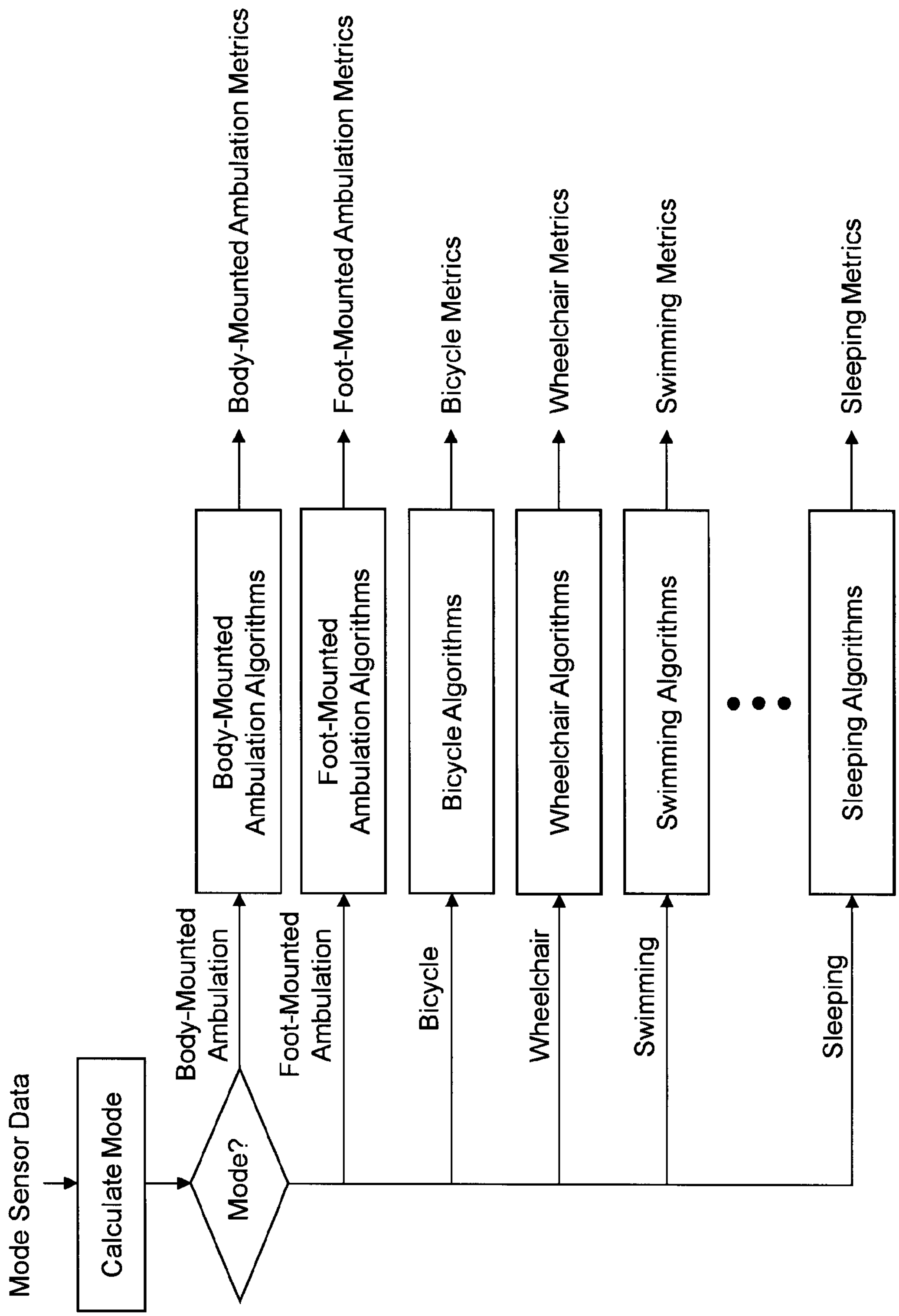

Mode Sensor Data
Calculate Mode
Mode?
Body-Mounted Ambulation
Foot-Mounted Ambulation
Bicycle
Wheelchair
Swimming
Sleeping
Body-Mounted Ambulation Algorithms
Foot-Mounted Ambulation Algorithms
Bicycle Algorithms
Wheelchair Algorithms
Swimming Algorithms
Sleeping Algorithms
Body-Mounted Ambulation Metrics
Foot-Mounted Ambulation Metrics
Bicycle Metrics
Wheelchair Metrics
Swimming Metrics
Sleeping Metrics

FIGURE 11B

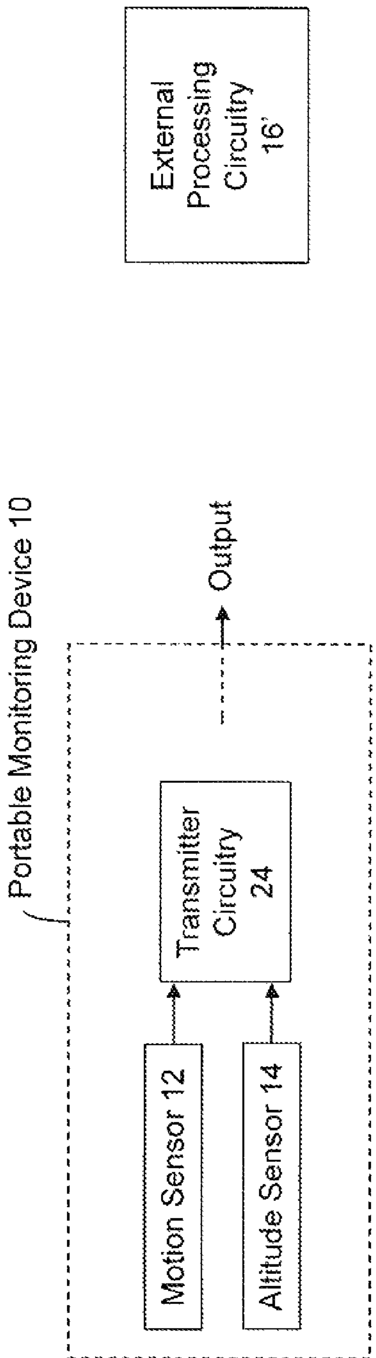


FIGURE 12A

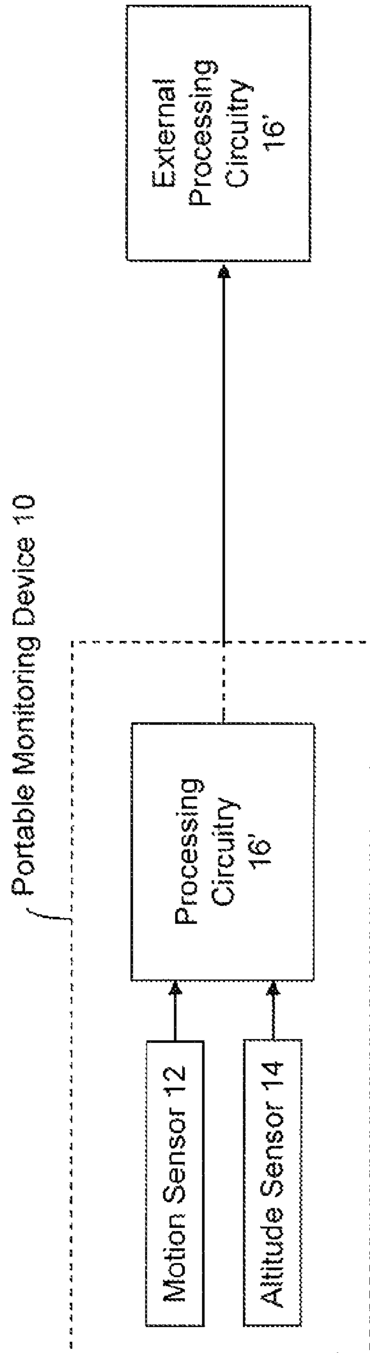
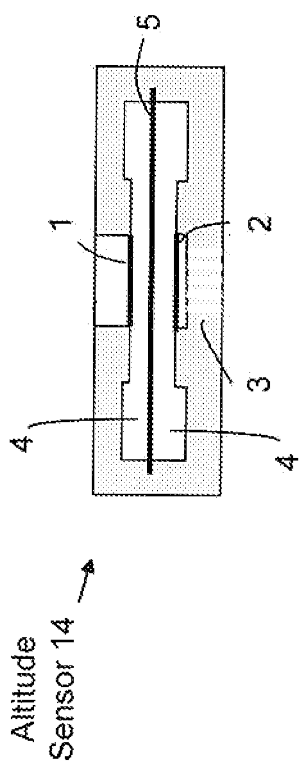


FIGURE 12B

FIGURE 13



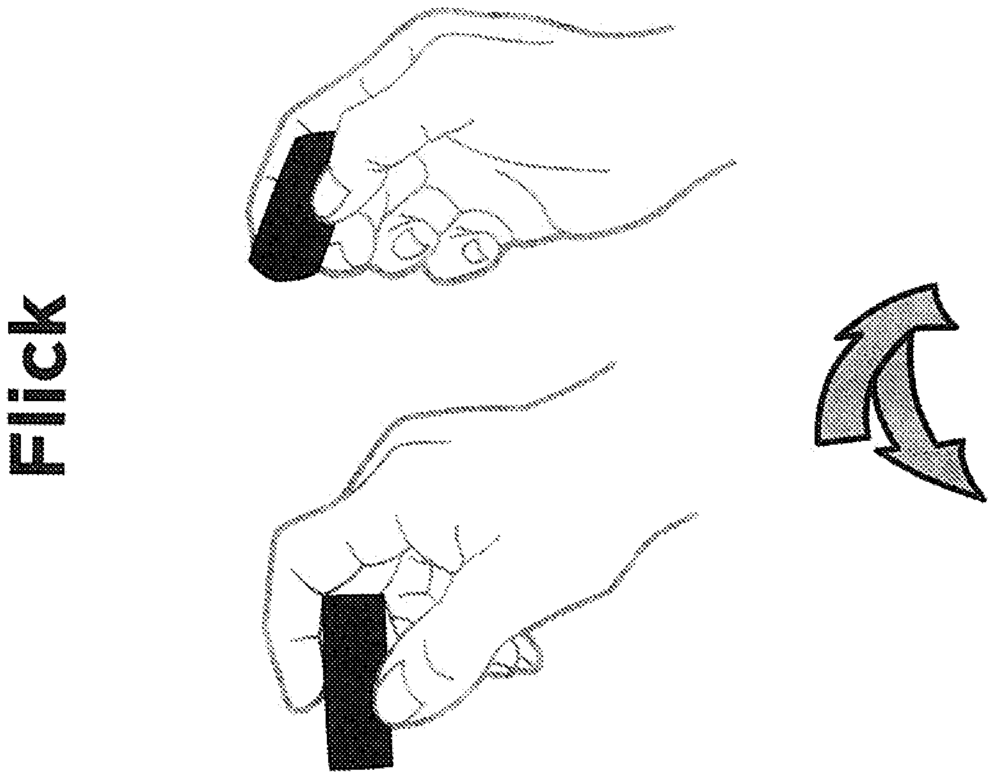


FIGURE 14

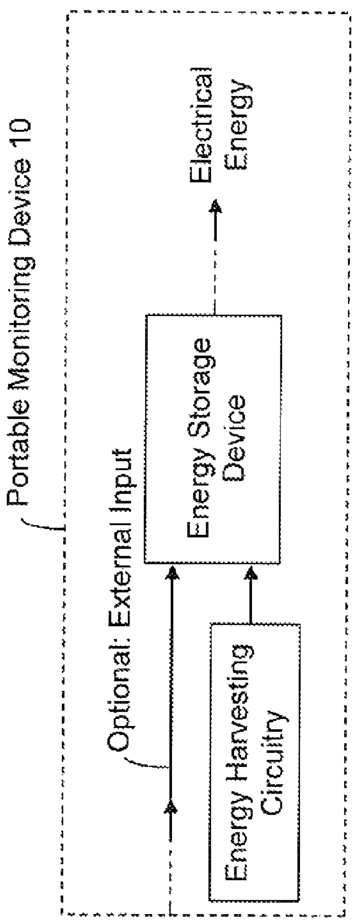


FIGURE 15A

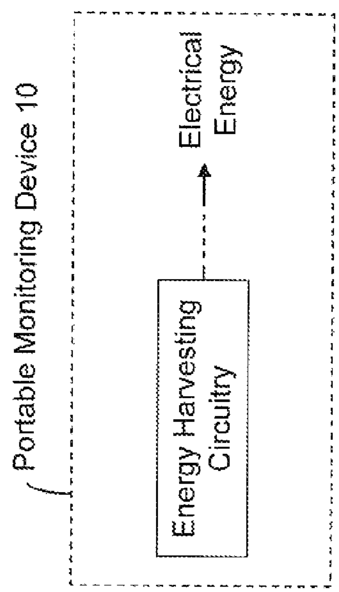


FIGURE 15B

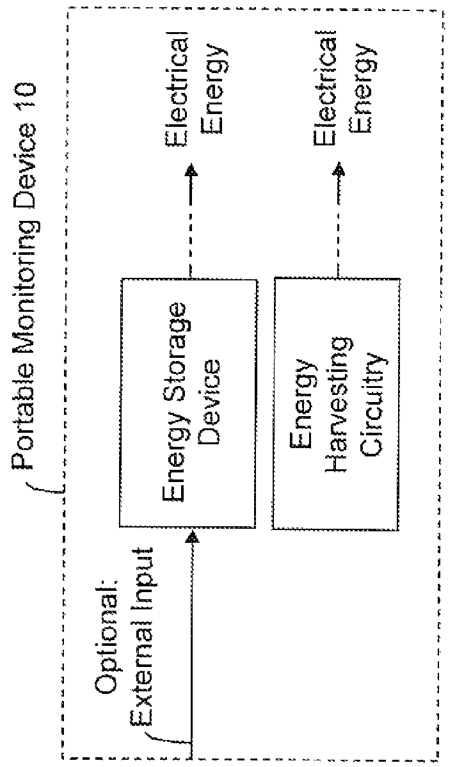


FIGURE 15C

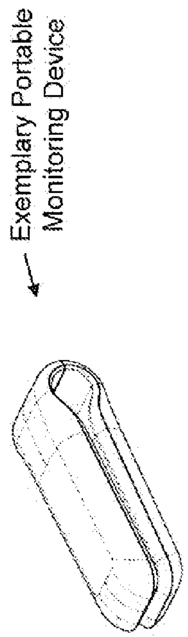
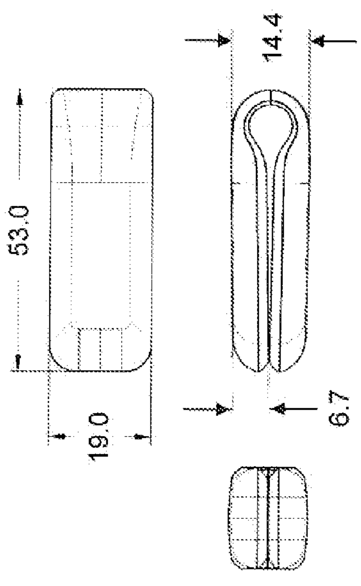


FIGURE 16A



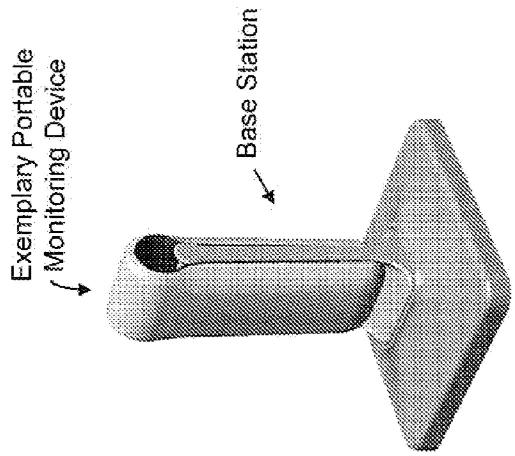


FIGURE 16C

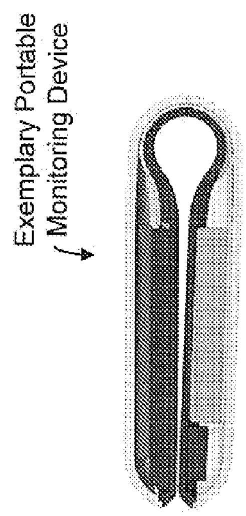


FIGURE 16B

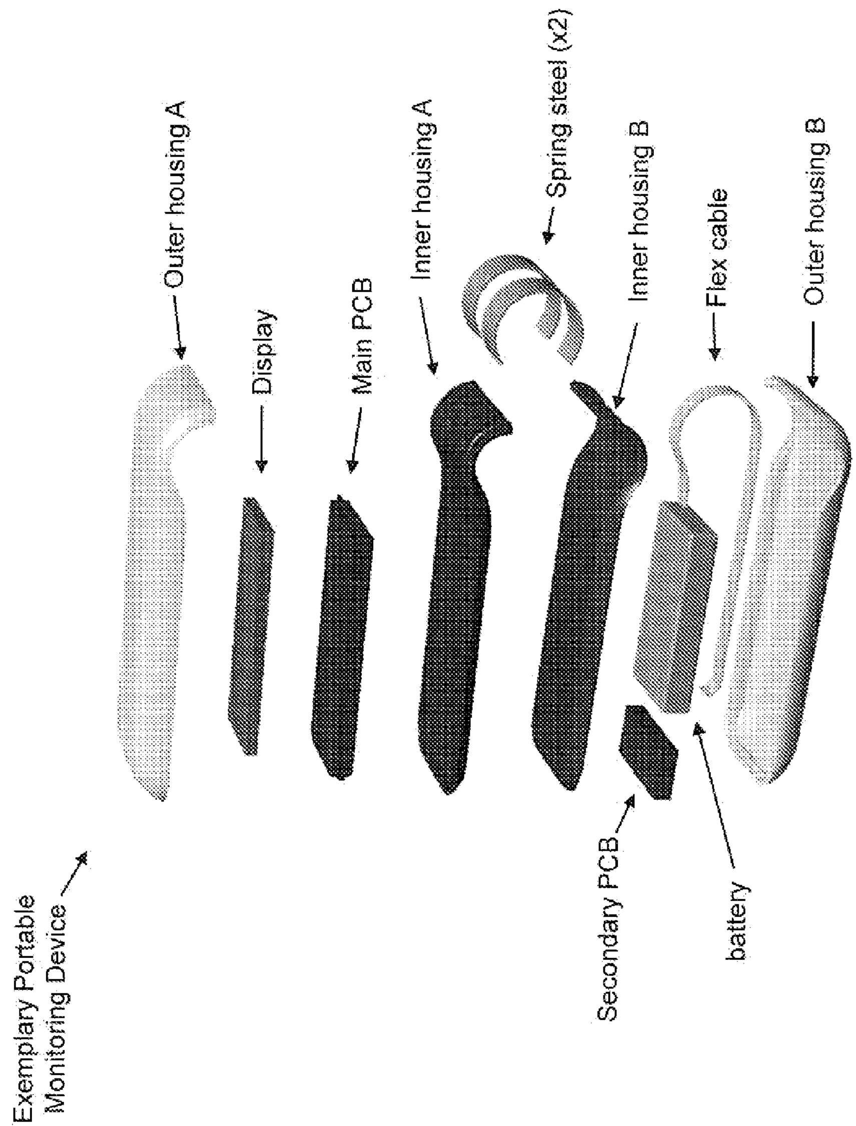

Outer housing A
Display
Main PCB
Inner housing A
Spring steel (x2)
Inner housing B
Flex cable
Outer housing B
Exemplary Portable Monitoring Device
Secondary PCB
battery

FIGURE 17

PORTABLE MONITORING DEVICES AND METHODS OF OPERATING SAME

RELATED APPLICATION

This application is a divisional of U.S. patent application Ser. No. 13/913,744, filed Jun. 10, 2013, entitled "Portable Monitoring Devices and Methods of Operating Same" (now U.S. Pat. No. 8,583,402), which is a divisional of U.S. patent application Ser. No. 13/667,242, filed Nov. 2, 2012, entitled "Portable Monitoring Devices and Methods of Operating Same" (now U.S. Pat. No. 8,463,576), which is a divisional of U.S. patent application Ser. No. 13/469,033, filed May 10, 2012, entitled "Portable Monitoring Devices and Methods of Operating Same" (now U.S. Pat. No. 8,311,770), which is a divisional of U.S. patent application Ser. No. 13/249,155, filed Sep. 29, 2011, entitled "Portable Monitoring Devices and Methods of Operating Same" (now U.S. Pat. No. 8,180, 592), which is a divisional of U.S. patent application Ser. No. 13/156,304, filed on Jun. 8, 2011, entitled "Portable Monitoring Devices and Methods of Operating Same", filed on September (still pending). This non-provisional application, and the aforementioned non-provisional applications, claim priority to U.S. Prov. App. No. 61/388,595, entitled "Portable Monitoring Devices and Methods of Operating Same", filed Sep. 30, 2010, and U.S. Prov. App. No. 61/390,811, entitled "Portable Monitoring Devices and Methods of Operating Same", filed Oct. 7, 2010; the contents of these U.S. Provisional Applications are incorporated by reference herein in their entirety.

INTRODUCTION

The present inventions relate to portable monitoring devices, and method of operating and controlling same, wherein the portable monitoring devices include an altitude sensor, motion sensor and processing circuitry to calculate, assess and/or determine calorie burn and/or other activity-related quantities of the user (for example, a human or non-human animal such as a dog, cat or horse). In these aspects, the present inventions employ the altitude sensor data and the motion sensor data to calculate, assess and/or determine the calorie burn and/or other activity-related quantities of the user (for example, number of steps and/or stairs, number of stair flights, elevation gain/loss from ambulatory and/or non-ambulatory locomotion, absolute elevation, elevation and/or activity points, activity intensity, distance traveled and/or pace, number of swim strokes and/or kicks, strokes per lap, lap time, pace and/or distance, number of pedal rotations of a bicycle, arm or wheel rotation of a wheelchair, heart rate, heart rate variability, respiration rate, stress levels, skin temperature, body temperature). In the following disclosure, use of the term "activity" includes sedentary and nonsedentary activities. As such, the present inventions also may be used to monitor activities related to sleeping, lying, sitting, and standing stationary and may provide corresponding metrics (for example, time asleep, the onset, duration, and number of awakenings while attempting to sleep, the time spent in various stages of sleep, sleep latency, sleep efficiency and other sleep quality parameters, the presence of sleep apnea and other diagnostic measures, time spent in a prone non-standing state, and resting heart rate).

In other aspects, the portable monitoring device of the present inventions may include a physiological sensor, in addition to the altitude sensor, motion sensor and processing circuitry. In these aspects, the present inventions employ the physiological sensor data, altitude sensor data and motion sensor data to calculate, assess and/or determine the calorie burn and/or such other activity-related quantities of the user.

In certain aspects the processing circuitry is partially or wholly disposed external to the portable monitoring device wherein the external processing circuitry receives partially processed or "raw" sensor data. Here, the external processing circuitry partially or wholly calculates, assesses and/or determines the calorie burn and/or other activity-related quantities of the user.

Notably, the present inventions also relate to techniques or methods of calculating, assessing and/or determining the calorie burn and/or other activity-related quantities of the user based on or using sensor data acquired by a portable monitoring device, for example, devices according to any of the of the present inventions.

BRIEF DESCRIPTION OF THE DRAWINGS

In the course of the detailed description to follow, reference will be made to the attached drawings. These drawings show different aspects of the present inventions and, where appropriate, reference numerals illustrating like structures, components, materials and/or elements in different figures are labeled similarly. It is understood that various combinations of the structures, components, and/or elements, other than those specifically shown, are contemplated and are within the scope of the present inventions.

Moreover, there are many inventions described and illustrated herein. The present inventions are neither limited to any single aspect nor embodiment thereof, nor to any combinations and/or permutations of such aspects and/or embodiments. Moreover, each of the aspects of the present inventions, and/or embodiments thereof, may be employed alone or in combination with one or more of the other aspects of the present inventions and/or embodiments thereof. For the sake of brevity, certain permutations and combinations are not discussed and/or illustrated separately herein.

FIGS. **1**A-**1**L are block diagram representations of exemplary portable monitoring devices, according to at least certain aspects of certain embodiments of the present inventions, wherein the portable monitoring devices, according to at least certain aspects of certain embodiments of the present inventions, include processing circuitry, one or more altitude sensors, one or more motion sensors and, in certain embodiments, one or more physiological sensors, one or more mode sensors, transmitter circuitry and/or receiver circuitry;

FIGS. **1**M-**1**X are block diagram representations of exemplary portable monitoring devices, according to at least certain aspects of certain embodiments of the present inventions, wherein the portable monitoring devices, according to at least certain aspects of certain embodiments of the present inventions, include one or more motion sensors, and, in certain embodiments, may also include processing circuitry, transmitter circuitry and/or receiver circuitry, one or more physiological sensors, and one or more mode sensors;

FIG. **2** is a block diagram representation of processing circuitry to calculate, assess and/or determine the calorie burn of the user based on sensor data; the processing circuitry may include memory (for example, Flash memory, DRAM and/or SRAM) to store, for example, (i) sensor data and (ii) information which is representative of calorie burn—for example, cumulative and/or over time; notably, the processing circuitry may be discrete or integrated logic, and/or one or more state machines, processors (suitably programmed) and/or field programmable gate arrays (or combinations of the aforementioned); indeed, any circuitry (for example, discrete or integrated logic, state machine(s), processor(s) (suitably pro-

grammed) and/or field programmable gate array(s) (or combinations of the aforementioned)) now known or later developed may be employed to calculate, determine, assess and/or determine the calorie burn of the user based on sensor data;

FIGS. **3**A and **3**B are block diagram representations of exemplary motion sensors which include, for example, one or more accelerometers, gyroscopes, compasses, switches (for example, mechanical), piezoelectric film and/or pedometers to determine, calculate and/or detect one or more steps of the user; notably, the exemplary motion sensor may be incorporated in any of the exemplary portable monitoring devices;

FIG. **3**C is a block diagram representation of one or more altitude sensor(s) that may be incorporated in the exemplary portable monitoring devices according to any of the exemplary embodiments of the present inventions;

FIGS. **4**A-**4**D, **4**F, **4**H-**4**J, and **4**M-**4**R are flowcharts of exemplary processes of calculating, obtaining, assessing and/or determining calorie burn of the user based on certain sensor data, according to certain aspects of the present inventions;

FIGS. **4**E and **4**G are flowcharts of exemplary processes for calculating, obtaining, assessing and/or determining other activity-related metrics including, for example, steps taken by the user based on certain sensor data, according to certain aspects of the present inventions;

FIGS. **4**K and **4**L are flowcharts exemplary of processes for calculating, obtaining, assessing and/or determining the activity state of the user (for example, walking or running on relative flat or level ground, traversing stairs, on an escalator or in an elevator, traversing a hill or the like), based on certain sensor data including the attitude sensor data and/or physiological sensor data, according to certain aspects of the invention; notably, hereinafter the activity state of the user may be indicated as the "user state";

FIGS. **5**A and **5**B are block diagram representations of the motion sensor in combination with flowcharts of exemplary processes of calculating, obtaining, assessing and/or determining calorie burn of the user based on speed data, according to certain aspects of the present inventions;

FIG. **6** is an example of determining the activity state of the user by evaluating the altitude sensor data based on or using algorithms or processes generally illustrated in the flowchart of FIG. **4**K wherein altitude data is depicted in the top panel and acceleration data is depicted in the bottom panel; in this exemplary data set and activity state determination, the walking segments are marked A, B, C and are determined by the pedometer function with each step marked as a red dot in the bottom panel; drawing indicator **1** identifies a period of altimeter measurement artifact that is disregarded because the user has not performed any steps; drawing indicator **2** identifies a period of walking that includes a 20 ft drop in apparent altitude due to motion artifact—this is disregarded because the user only walked four steps during this interval, so Δh/Δstep=−5 ft/step, which is likely not humanly possible under normal circumstances; drawing indicator **3** identifies a period of walking on stairs: 20 steps for a total height increase of 10 ft (Δh/Δstep=0.5 ft/step) and is used to update the appropriate activity metrics; drawing indicator **4** identifies a period of walking up an escalator: 24 steps over 32 ft (Δh/Δstep=1.3 ft/step) and is used to update the appropriate activity metrics, taking into account that the activity was partially assisted; drawing indicator **5** identifies a period of walking up a hill: 350 steps for a height increase of 33 ft (Δh/Δstep=0.1 ft/step) and is used to update the appropriate activity metrics;

FIG. **7** is a block diagram representation of one or more physiological sensor(s) to determine, sense, detect, assess and/or obtain information which is representative of physiological information of the user, according to at least certain embodiments of the present inventions; notably, the one or more physiological sensor(s) may be incorporated in and/or coupled to the exemplary portable monitoring devices (for example, physically, electrically and/or optically coupled, including wired and/or wirelessly coupled) according to at least certain embodiments of the present inventions;

FIGS. **8**A-**8**G are flowcharts of exemplary processes or logic employed by the processing circuitry (for example, a state machine) to determine, estimate and/or calculate changes in altitude), according to certain aspects of the present inventions;

FIG. **8**H is a flowchart of an exemplary process or logic to compute, estimate and/or determine a number of stair steps traversed by the user (for example, the number of upward stair steps), according to certain aspects of the present inventions; notably, in this exemplary embodiment, when ΔH-S and ΔH-t meet a first criteria, the processing circuitry determines, calculates and/or estimates an onset of the first step of the stair sequence;

FIGS. **9**A-**9**D are flowcharts of exemplary processes of controlling, adjusting and/or determining a sampling frequency of the altitude sensor (F_{ALT}) based on or using data which is representative of motion of the user (for example, from a motion sensor of the portable monitoring device), according to certain aspects of the present inventions; notably FIG. **9**D illustrates an embodiment of the portable monitoring device where sampling of the altitude sensor is determined or triggered based on or using step events detected by a motion sensor (for example, a pedometer), or a maximum time T between samples (whichever occurs first);

FIGS. **10**A-**10**F are block diagram representations of exemplary user interfaces of the exemplary portable monitoring devices according to at least certain embodiments of the present inventions; in these exemplary illustrative embodiments, the user interface includes output mechanisms (for example, a display and/or speaker) and input mechanism (for example, switches, a microphone, and vibration and gesture recognition sensor(s), wherein the user may input data and/or commands); notably, any manner of and/or mechanism for outputting and/or inputting of data and/or commands (for example, responses to, for example, queries) are intended to fall within the scope of the present inventions;

FIGS. **11**A and **11**B are flowcharts of exemplary processes of calculating, obtaining, assessing and/or determining calorie burn and other activity-related metrics for the user based on, among other things, data from one or more mode sensors; notably, with respect to FIG. **11**B, "Body-Mounted Ambulation Metrics" includes Output Steps, Pace, Distance, Calorie Burn, Heart Rate, HRV, Activity Intensity, Heart Rate Zones, Altitude Gain, Stair Steps and/or Elevation Points, "Foot-Mounted Ambulation Metrics" includes Output Steps, Pace, Distance, Calorie Burn, Activity Intensity, Heart Rate Zones, Altitude Gain, Stair Steps and/or Elevation Points, "Bicycle Metrics" includes Output Altitude Gain, Speed, Distance, Cadence, Calorie Burn, Activity Intensity and/or Elevation Points, "Wheelchair Metrics" includes Output Altitude Gain, Speed, Distance, Wheel Spins, Cadence, Calorie Burn, Activity Intensity and/or Elevation Points, "Swimming Metrics" includes Output Depth, Speed, Distance, Laps, Lap Time, Strokes, Drift Time, Turnaround Time, Calorie Burn, Stroke Type, Heart Rate, HRV, Activity Intensity and/or Heart Rate Zones, and "Sleeping Metrics" includes Output Sleep Latency, Number, Duration, and Onset of Awakenings, Sleep Apnea Detection, Resting Heart Rate, Calorie Burn, Duration and Onset of Sleep Stages;

FIG. **12**A is a block diagram representation of exemplary portable monitoring devices, according to at least certain aspects of certain embodiments of the present inventions, wherein the portable monitoring devices, according to at least certain aspects of certain embodiments of the present inventions, includes an altitude sensor and a motion sensor, and wherein the processing circuitry is external to the portable monitoring devices calculates or determines energy and/or calorie "burn" and/or other activity metrics due to activity of the user using altitude and motion sensor data; notably, other embodiments of the portable monitoring device of this aspect may also include one or more physiological sensors, one or more mode sensors, transmitter circuitry and/or receiver circuitry; for example, any portable monitoring device of the present inventions may employ or be implemented in any embodiment where the processing circuitry is disposed external to the portable monitoring device;

FIG. **12**B is a block diagram representation of exemplary portable monitoring devices, according to at least certain aspects of certain embodiments of the present inventions, wherein the portable monitoring devices, according to at least certain aspects of certain embodiments of the present inventions, includes an altitude sensor, a motion sensor, and certain processing circuitry—wherein certain other processing circuitry is external to the portable monitoring devices and the processing circuitry, in combination, calculates or determines energy and/or calorie "burn" and/or other activity metrics due to activity of the user using altitude and motion sensor data; notably, other embodiments of the portable monitoring device of this aspect may also include one or more physiological sensors, one or more mode sensors, transmitter circuitry and/or receiver circuitry; for example, any portable monitoring device of the present inventions may employ or be implemented in any embodiment where the processing circuitry is disposed external to the portable monitoring device;

FIG. **13** is a cross-sectional representational view of an altitude sensing microelectromechanical system (MEMS) to sense, sample, determine and/or obtain altitude data, according to at least certain aspects of certain embodiments of the present inventions; notably, the altitude sensing MEMS of FIG. **13** may be incorporated in any of the exemplary portable monitoring devices of the present inventions;

FIG. **14** illustrates an exemplary gesture of the portable monitoring device that is mostly contained in the orthogonal plane to the gravitational vector which may be used as a user interface mechanism (e.g., to navigate a menu system);

FIGS. **15**A-**15**C are block diagram representations of exemplary portable monitoring devices including energy storage device (for example, a battery and/or ultracapacitor(s)) and/or energy harvesting circuitry wherein energy acquired, obtained and/or generated by the energy harvesting circuitry is employed to immediately power the device or stored in energy storage device; according to at least certain embodiments of the present inventions;

FIGS. **16**A and **16**B illustrates different views of an exemplary embodiment of the portable monitoring device according to certain aspects of the present inventions; notably, exemplary physical specifications or dimensions (in millimeters) are outlined in connection with the top down and side views of FIG. **16**A;

FIG. **16**C illustrates an exemplary embodiment of the portable monitoring device of FIGS. **16**A and **16**B disposed on a base station; and

FIG. **17** illustrates, in exploded view form, an exemplary embodiment of the portable monitoring device of FIGS. **16**A and **16**B, according to certain aspects of the present inventions; notably, the sensors (for example, motion, altitude and/or physiological sensors) may be disposed on the main PCB.

Again, there are many inventions described and illustrated herein. The present inventions are neither limited to any single aspect nor embodiment thereof, nor to any combinations and/or permutations of such aspects and/or embodiments. Each of the aspects of the present inventions, and/or embodiments thereof, may be employed alone or in combination with one or more of the other aspects of the present inventions and/or embodiments thereof. For the sake of brevity, many of those combinations and permutations are not discussed separately herein.

DETAILED DESCRIPTION

There are many inventions described and illustrated herein. In one aspect, the present inventions are directed to portable monitoring devices, and method of operating and controlling same, which monitor, calculate, determine and/or detect energy and/or calorie "burn" due to physical activity of the user (for example, a human or non-human animal) and/or other activity-related metrics. The portable monitoring devices of the present inventions include an altitude sensor, motion sensor and processing circuitry to calculate, assess and/or determine the calorie burn of the user and/or other activity-related metrics. (See, for example, FIG. **1**A). In one embodiment, at least a portion of the portable monitoring device (including the one or more altitude sensors and/or motion sensors) is affixed to the user during operation wherein the housing of the device includes a physical size and shape that facilitates coupling to the user, for example, the body of the user (such as, for example, arm, wrist, angle, waist and/or foot) and allows the user to perform normal or typical user activities (including, for example, exercise of all kinds and type) without hindering the user from performing such activities. The portable monitoring device may include a mechanism (for example, a clip, strap and/or tie) that facilitates coupling or affixing the device to the user during such normal or typical user activities.

Briefly, during operation, the altitude sensor generates data which is representative of the altitude and/or changes in altitude of the user. The motion sensor generates data which is representative of motion of the user. The processing circuitry, using (i) data which is representative of the altitude and/or changes in altitude and (ii) data which is representative of the motion of the user, determines, calculates, assesses, estimates and/or detects energy and/or calorie "burn" of the user. (See, FIG. **2**).

Notably, the processing circuitry may also calculate, assess, estimate and/or determine other activity-related metrics including, for example, (i) in the context of running/walking on level, substantially level, or relatively level ground, (a) number of steps, which may be categorized according to the number of steps associated with a user state, for example, walking, jogging and/or running, (b) distance traveled and/or (c) pace, (ii) in the context of running/jogging/walking/jumping on stairs, hills or ground having a grade of greater than, for example, about 3%, (a) number of stair and/or hill steps, which may be categorized, correlated or organized/arranged according to the number of stair and/or hill steps pertaining to, for example, the speed, pace and/or user state of the user (for example, walking, jogging and/or running), (b) number of flights of stairs, (c) ascent/descent distance on stairs and/or hills, (d) pace, (e) ascent/descent on elevators and/or escalators, (f) number of calories burned or expended by walking/running on stairs and/or hills and/or (g) quantify/compare the additional calories expended or burnt

from stairs/hills relative to, versus or over level ground, (iii) in the context of swimming, number of strokes, time between strokes, leg kicks and similar metrics (variance of stroke time, mean stroke time, etc.), depth underwater, strokes per lap, lap time, pace and/or distance, (iv) in the context of using a bicycle, wheelchair, skateboard, skis, snowboard, ladder, etc., (a) ascent/descent distance traversed, (b) number of additional calories expended, (c) time of a downward "run" or upward "climb", (d) number of calories expended, (e) number of pedal rotations, (f) arm or wheel rotation, (g) the grade of the surface, (h) pushes, kicks and/or steps. This list of activities (if applicable to the particular embodiment) is merely exemplary and is not intended to be exhaustive or limiting of the inventions to, for example, the precise forms, techniques, flow, and/or configurations disclosed.

The processing circuitry may be discrete or integrated logic, and/or one or more state machines, processors (suitably programmed) and/or field programmable gate arrays (or combinations thereof); indeed, any circuitry (for example, discrete or integrated logic, state machine(s), special or general purpose processor(s) (suitably programmed) and/or field programmable gate array(s) (or combinations thereof)) now known or later developed may be employed to calculate, determine, assess, estimate and/or determine the calorie burn of the user based on sensor data. In operation, the processing circuitry may perform or execute one or more applications, routines, programs and/or data structures that implement particular methods, techniques, tasks or operations described and illustrated herein. The functionality of the applications, routines or programs may be combined or distributed. Further, the applications, routines or programs may be implemented by the processing circuitry using any programming language whether now known or later developed, including, for example, assembly, FORTRAN, C, C++, and BASIC, whether compiled or uncompiled code; all of which are intended to fall within the scope of the present invention.

With reference to FIG. **3**A, in one embodiment, the motion sensor may include an accelerometer and pedometer to assess the character of the motion/step and determine the number of user steps. In this embodiment, the output of the accelerometer is analyzed by the pedometer to assess the character of the motion/step and determine the number of user steps. With reference to FIG. **3**B, in addition to the accelerometer(s), or in lieu thereof, the motion sensor may include one or more gyroscopes, piezofilms, contact switches, and all combinations thereof, with or without the pedometer. Moreover, motion as inferred through GPS, compasses, wireless methods such as proximity sensing to a reference position/device, and other non-inertial sensing approaches (and their combinations with the aforementioned inertial sensors) may also be employed alone or in conjunction with any of the other configurations and/or techniques. Indeed, all types of sensors and sensing techniques, whether now known or later developed, that generate data which is representative of motion of the user are intended to fall within the scope of the present inventions.

With reference to FIG. **3**C, in one embodiment, the altitude sensor may include a pressure sensor (relative/differential or absolute), GPS, barometer, radar, ladar (i.e., laser detection and ranging), and/or infrared proximity sensor. The portable device may also employ wireless signal strength, visual landmark identification, or optical proximity sensing to a known reference position/device to provide data which is representative of elevation. In this regard, the altitude sensor provides data which is representative of the altitude and/or changes in altitude of the user. Indeed, all types of sensors and sensing techniques, whether now known or later developed, that generate data which is representative of the altitude and/or changes in altitude of the user are intended to fall within the scope of the present inventions.

As mentioned above, the processing circuitry employs (i) data which is representative of the altitude and/or changes in altitude and (ii) data which is representative of the motion of the user, to determine, calculate and/or detect energy and/or calorie "burn" of the user. (See, FIG. **2**). In one embodiment, the processing circuitry implements algorithms and/or processes data based on the flowchart of FIG. **4**A. For example, with reference to FIGS. **4**A and **4**B, the processing circuitry receives the motion sensor data and determines or calculates the calorie burn based on, for example, the character of the motion/step and the number of user steps. The processing circuitry, using the altitude sensor data, may adjust the calorie burn based on consideration or analysis of the data from the altitude sensor. In this regard, the processing circuitry may assess or determine the type of motion that produces/causes the altitude or change in altitude and, in response thereto, determine or calculate the user state—that is, activity state of the user which temporally coincides with the motion sensor data—for example, walking or running on relatively flat or level ground, traversing stairs, on an escalator or in an elevator, traversing a hill or the like. In response to the user state, the processing circuitry may generate an adjusted calorie burn. Here, the processing circuitry adjusts the calculated calorie burn with a factor that is based on the activity state of the user as determined by the altitude sensor data. Thus, the processing circuitry correlates the (i) data which is representative of the altitude and/or changes in altitude and (ii) data which is representative of the motion of the user, to determine or calculate energy and/or calorie "burn" of the user.

With reference to FIGS. **4**C and **4**D, in one embodiment, the processing circuitry evaluates (i) data which is representative of the altitude and/or changes in altitude and (ii) data which is representative of the motion of the user, to identify, determine or calculate the user state and, in response thereto, implement a user state specific algorithm or methodology to determine or calculate energy and/or calorie "burn" of the user. For example, where the processing circuitry evaluates such data to determine that the user is traversing a hill, the processing circuitry employs a "hill" specific algorithm to determine or calculate the energy and/or calorie "burn" using the (i) data which is representative of the altitude and/or changes in altitude and (ii) data which is representative of the motion of the user. In this way, the determination or calculation of the energy and/or calorie "burn" may be more accurate in that the specific or dedicated algorithm may employ considerations or features that are "unique" and/or specific to the associated activity; and, as such, the specific or dedicated algorithm may be tailored to the considerations or features that are "unique" and/or specific to the associated activity.

The processing circuitry may calculate, determine and/or estimate calorie consumption, burn and/or expenditure using any technique now known, described herein, and/or later developed. In one exemplary embodiment, the processing circuitry employs a calorie consumption technique that estimates consumption, burn and/or expenditure for walking, running, and lifestyle activities as follows.

Speed-Based Estimation, Calculation and/or Determination

In one embodiment, the processing circuitry may estimate calorie expenditure and activity level based on or using, partially or entirely, the ambulatory speed of the user. For example, with reference to FIG. **5**A, in one embodiment, the calorie consumption, burn and/or expenditure is calculated, determined and/or estimated as a function of the speed of the

user. Representative energy expenditure rates expressed as metabolic equivalents per minute (MET/min) at different speeds are provided in TABLE 1.

TABLE 1

Speed (mph)	Metabolic Equivalents (MET/min)
Running, 5.0	8.0
Running, 5.2	9.0
Running, 6.0	10.0
Running, 6.7	11.0
Running, 7.0	11.5
Running, 7.5	12.5
Running, 8.0	13.5
Running, 8.6	14.0
Running, 9	15.0
Running, 10.0	16.0
Running, 10.9	18.0
Walking, 1.86	1.5
Walking, 2.24	1.9
Walking, 2.61	2.4
Walking, 2.98	3.2
Walking, 3.36	4.0
Walking, 3.73	5.0
Walking, 4.10	6.4

Exemplary running and walking energy expenditure (MET/min) by speed

In one embodiment, the speed of the user may be calculated, determined and/or estimated as the user's step count over a time epoch multiplied by one or more step lengths of the user (which may be programmed, predetermined and/or estimated (for example, based on attributes of the user (for example, height, weight, age, leg length, and/or gender))), which may be estimated, obtained (for example, from a look-up table or database) and/or interpolated from the MET table to obtain the user's energy expenditure. In one embodiment, step length may take one of two values that are indicative of a walking and a running step length dependent on the step frequency and/or acceleration characteristics of the user. In a preferred embodiment, step length may be described as a linear function of step frequency:

$$\text{step length} = A + B^{*}\text{step frequency},$$

where A and B are parameters that may be associated with or calibrated to the user; notably, such parameters may be stored in memory in the portable monitoring device.

In another embodiment, step length may be described as a function of step frequency and characteristics of the user acceleration:

$$\text{step length} = A + B^{*}\text{step frequency} + C^{*}\text{variance of acceleration},$$

where A, B, and C are parameters that may be calibrated to the user; notably, such parameters may be stored in memory in the portable monitoring device.

In yet another embodiment, step length may be obtained, acquired and/or determined via a look-up table or database, or interpolated (e.g., spline interpolation, neural network) between known (step frequency, step length) pairs or (step frequency, acceleration variance, step length) triplets that have been predetermined or specified by the user and/or pre-programmed or calibrated using the device. For example, the user may start an annotated walking or running sequence on the portable monitoring device, then specify the distance traveled either on the device or through another service (e.g., www.fitbit.com), which may be employed to calibrate or reference for the device by one or more of the following:

estimating the regression coefficients (A, B) or (A, B, C), calculating a walking and/or running step length, and building a lookup table for (step frequency, step length) or (step frequency, acceleration variance, step length).

In addition thereto, or in lieu thereof, the user may calibrate the portable monitoring device by attaching the device to the foot of the user and placing the device into an annotated foot-mounted mode in which speed and distance are tracked and need not be entered by the user. In this mode, the portable monitoring device also acquires data which is representative of, for example, the user's step frequency, acceleration variance, step length. Likewise, distance may be derived from other sources such as a GPS-enabled mobile device, a software mapping utility, or other distance tracking device (e.g., Nike+) and employed to determine the step frequency, acceleration variance, and step length of the user. Under certain conditions, in the absence or interruption of GPS signal, the combination of user altitude over time, two or more geophysical positions on a map and the times at which the user was there, a corresponding altitude map, and the distance over time of the user may be used to estimate the complete route traveled by the user.

Although, in the preceding examples, the step length has been characterized, expressed and/or estimated as a linear function of one or more parameters such as step frequency and variance of acceleration, the step length and other parameter may be characterized, expressed and/or estimated to a higher order or different functional form. Accordingly such parameters may be expressed as polynomial functions, transcendental functions, etc. as well and may include other input variables such as elevation change (as discussed in detail herein). Indeed, the function need not be monotonically increasing or monotonically decreasing, as implied by the preceding illustrative linear functions. Additionally, different equations may be employed for specific activity states or operating modes (e.g., walking, running, jumping, speed walking).

The speed value may be converted to calorie expenditure by multiplying the corresponding MET value by the user's BMR. BMR may be obtained through any of a number of well-known equations based on height, weight, gender, age, and/or athletic ability or through designated BMR measurement devices. For example, a user may have a running step length of 57 inches and take 180 running steps during 1 min. Using the method described above, the user's speed estimate is 9.8 miles per hour, which may be linearly interpolated to provide a BMR value of 15.8 MET from the MET table above. Assuming the user's BMR to be 1.10 kcal/MET, the calorie burn of the user in the preceding minute is 17.4 kcal. For the avoidance of doubt, this description is intended to be exemplary.

Speed estimation may be determined using a different time epoch or a plurality of time epochs. Multiple step lengths may be used. The MET table may be calibrated to the specific user and/or may be expressed as a function of speed in some method, such as an analytical function, discontinuous function, or otherwise. For example, in one embodiment, the relationship between speed and calories may be expressed as:

$$\text{cal\_speed} = (A + B^{*}\text{speed})^{*}\text{time}^{*}BMR,$$

where speed is the speed of the user, time is the length of time under consideration, and (A,B) are parameters that may be calibrated to the user; notably, such parameters may be stored in memory in the portable monitoring device.

Likewise, it is noted that an intermediate MET calculation step is not required in this and similar methods. Calorie expenditure may be calculated directly based on speed and one or more physiological parameters of the user such as age,

gender, height, weight, and/or athletic ability. Speed may also be filtered over time rather than accepted as a "raw" measurement for a given time epoch.

FIG. **5**B illustrates another embodiment in which the portable monitoring device may calculate, estimate and/or determine the speed of the user based on linear and angular acceleration measurements from, for instance, the foot. Linear acceleration may be obtained from one or more accelerometers. Angular acceleration may be obtained by one or more accelerometers, one or more gyroscopes, and/or one or more orientation sensors (e.g., compass).

Notably, the portable monitoring device may employ such techniques as those set forth in U.S. Pat. Nos. 6,513,381 and/or 5,724,265. Alternatively, the portable monitoring device may employ the techniques set forth in U.S. Pat. Nos. 4,578,769 and 6,018,705 wherein the device is mounted to the foot of the user and the speed of the user may be estimated by the time of contact of the foot on the ground.

In one embodiment, the speed of the user may be determined, calculated and/or estimated from the signal energy from a motion sensor in the following form:

$$\text{speed}=A*\log(\text{energy})+B$$

where (A,B) are parameters that may be estimated or associated with and/or calibrated or tuned to an individual (for example, based on the physical or motion attributes of the user); notably, such parameters may be stored in memory in the portable monitoring device.

In yet another embodiment, the portable monitoring device (or associated device) may be location aware and the travel that coincides with motion detected by the motion sensor may be used to estimate speed. For example, the portable monitoring device may include or incorporate GPS to determine its location, or communicate with a GPS-enabled device to receive data which is representative of location or change in location (absolute or relative location data). In addition thereto, or in lieu thereof, the portable monitoring device may communicate wirelessly with RF location beacons to determine position and/or change in position. Indeed, the portable monitoring device may also use signal strength to the beacons to determine or estimate position and/or change therein.

In one embodiment, the portable monitoring device includes a camera (or communicates with a device that includes a camera). In this embodiment, the portable monitoring device may determine location visually by recognizing location landmarks and/or features.

Notably, the aforementioned location sensors and methods may also be used to infer user altitude. For example, the user's location as determined by GPS may enable altitude estimates when combined with an altitude map. GPS itself may also provide altitude measurements. Wireless communications may also be used to determine altitude. For example, a RF location beacon may be programmed with its altitude or the portable monitoring device may use any of a number of well known methods for three-dimensional point locating such as multilateration and trilateration.

Notably, the present inventions not intended to limit the method or means by which speed may be calculated, estimated and/or determined. Indeed, all forms of speed estimation, and mechanisms to implement such techniques, whether now known, described herein, a combination and/or fusion of the methods described herein, and/or later developed may be employed or implemented and, as such, are intended to fall within the scope of the present inventions.

Accelerometry for Calorie Estimation, Calculation and/or Determination

In addition to speed based techniques, or in lieu thereof, the portable monitoring device may estimate, calculate and/or determine, calorie consumption, burn and/or expenditure using data which is representative of the intensity of user motion—for example, as provided or determined by one or more single axis or multi-axis accelerometers. In one embodiment, the signals from the one or more accelerometers may be filtered using time domain or frequency domain filtering techniques to produce a parameter indicative of the intensity of user motion, often referred to as a "count". A count may be computed as the sum of the rectified filtered accelerometer output taken over a suitable time epoch, for example, 10 sec, with or without additional processing such as thresholding and/or saturation. The portable monitoring device may calculate, determine and/or estimate calorie consumption, burn and/or expenditure as a function of the current count value or a sequence of count values. For example, the portable monitoring device may calculate, determine and/or estimate calorie consumption, burn and/or expenditure using one or more of the following techniques:

$$MET=(A+B*\text{count})*\text{time},$$

$$MET=(A+B*\text{count}+C*\text{count}^2+D*\text{count}^3+\ldots)*\text{time}, \text{ and}$$

$$MET=(A*\exp(B*\text{count}))*\text{time},$$

which are, respectively, linear, polynomial, and exponential relationships between counts and calorie expenditure expressed in METs.

Notably, the preceding equations may likewise be expressed directly in terms of kilocalories through the inclusion of one or more physiological parameters such as the user's age, gender, height, weight, and/or athletic ability (wherein such parameters may also be set to default values). A representative example is the following:

$$\text{cal}=((A+B*\text{age}+C*\text{gender}+D*\text{weight}+E*\text{height}+F*\text{athleticism})*\text{count})*\text{time}.$$

Indeed, all accelerometry methods, whether now known or later developed, that generate data which is representative of the calorie burn of the user are intended to fall within the scope of the present inventions.

Heart Rate for Calorie Estimation, Calculation and/or Determination

In addition to speed based techniques and/or acceleration based techniques, or in lieu thereof, the portable monitoring device may estimate, calculate and/or determine calorie consumption, burn and/or expenditure using or based on a heart rate of the user. For example, in one embodiment, the portable monitoring device may estimate, calculate and/or determine calorie consumption, burn and/or expenditure as follows:

$$\text{cal}=(A*\text{HR}+B)*\text{time},$$

where HR is heart rate, time is the length of time under consideration, and A and B are parameters that may be adjusted or calibrated to the user based on, for example, the user's height, weight, age, gender, and/or athletic ability; notably, such parameters may be stored in memory in the portable monitoring device.

In one embodiment, the portable monitoring device may estimate, calculate and/or determine calorie consumption, burn and/or expenditure using a plurality of equations. For instance, at low or normal heart rates, it may be desirable to use one form of the above equation with parameters (A**1**,B**1**)

and at higher heart rates, it may be desirable to use the above equation with parameters (A**2**,B**2**).

"Combined" Calorie Consumption Estimation, Calculation and/or Determination

As indicated above, the portable monitoring device may estimate, calculate and/or determine calorie consumption, burn and/or expenditure using a combination of the techniques described herein. For example, with reference to FIG. **4**P, the portable monitoring device may employ motion data and heart rate data to estimate, calculate and/or determine calorie consumption, burn and/or expenditure. In this exemplary embodiment, under certain criteria such as low or normal heart rate in the absence of user steps, calorie burn is calculated, determined or estimated (for example, solely) using data which is representative of accelerometry while under other criteria such as elevated heart rate in the absence of user steps, calorie burn is calculated, determined or estimated (for example, solely) using data which is representative of the heart rate, otherwise calorie burn is calculated, determined or estimated using data which is representative heart rate, speed, and accelerometry. An example would be the following equation:

$$\text{cal\_total}=(p1*\text{cal\_HR}+p2*\text{cal\_speed}+p3*\text{cal\_accelerometry})*\text{time},$$

where cal_HR is the calorie estimate derived solely from heart rate, cal_speed is the calorie estimate derived solely from speed, and cal_accelerometry is the calorie estimate derived solely from accelerometry, time is the length of time under consideration, and pi (1, 2, 3) are either fixed parameters or dynamically adjusted parameters indicative of the certainty and/or quality of the preceding calorie estimates.

As such, the portable monitoring device may estimate, calculate and/or determine calorie consumption, burn and/or expenditure based on:

$$cal\text{\_total}=f(\text{heart rate data,motion data,mode data,time data}),$$

where f(•) is an arbitrary function that employs, fuses and/or implements information from the heart rate, motion, mode, and/or time, when such data is present and desirable or required.

In this context, information includes heart rate, heart rate variability, respiration as obtained as a modulated signal in an optical heart rate sensor, acceleration (raw, filtered, rectified, etc.), steps, speed, type of activity (e.g., bicycle, swimming, running, sleeping, sitting), surface slope, stairs, etc.

Notably, the aforementioned expression is intended to describe the case in which a plurality of equations are maintained and the portable monitoring device employs or selects a suitable, correct or predetermined equation is depending on, for example, the heart rate and/or motion as measured by the motion sensor and/or mode sensor.

The portable monitoring device may be mounted on or to different locations on the body of the user and/or exercise equipment and provides different capabilities based on its body location. In one embodiment, the portable monitoring device may obtain or determine its body location through a user input, a mode sensor that senses its body location and/or the presence of or coupling to a mounting or attachment mechanism or system (for example, which provides information to the device which indicates a mode).

In addition thereto, or in lieu thereof, the portable monitoring device may determine its body location automatically based on the signals derived from its other sensors. For example, the motion as observed by the accelerometer and/or gyroscope and/or compass and/or altimeter may be indicative of the device being mounted or affixed to the user's foot, hip, chest, back, or on the user's bicycle hub or wheelchair wheel. Moreover, an optical heart rate sensor may provide information (for example, supplementary information) to determine if the portable monitoring device is in contact with the user's skin and able to observe cardiac signal or otherwise in contact with a housing and/or mounting device. FIG. **4**Q illustrates an exemplary flow to calculate, estimate and/or determine calorie burn in such a system/technique. Notably, the portable monitoring device may calculate other parameters (in addition to or in lieu of calorie burn) which are not depicted in FIG. **4**Q and that are specific to the activity/mode that the device is currently in (for example, number of steps and/or stairs, number of stair flights, elevation gain/loss from ambulatory and/or non-ambulatory locomotion, absolute elevation, activity intensity, distance traveled and/or pace, number of swim strokes and/or kicks, strokes per lap, lap time, pace and/or distance, number of pedal rotations of a bicycle, arm or wheel rotation of a wheelchair, heart rate, heart rate variability, respiration rate, stress levels, skin temperature, body temperature). Calorie burn may be determined in a multitude of ways not depicted here. For example, the calories burned during swimming may be expressed as:

$$\text{cal\_swim}=(A+B*\text{speed})*\text{time},$$

where speed is the swimming speed of the user, time is the length of time under consideration, and (A,B) are parameters that may be associated with and/or calibrated or tuned to the user; notably, such parameters may be stored in memory in the portable monitoring device.

Where the portable monitoring device determines or is instructed that the user is swimming, speed may be calculated as the length of the pool divided by the time taken to cover that distance; from which an average distance traveled per stroke (as observed by the motion sensor) may be calculated, estimated and/or determined and subsequent calculations or estimates of speed may be determined by the observance of swim strokes in real-time:

$$\text{cal\_swim}=A+B*\text{stroke},$$

where stroke is the stroke count of the user and (A,B) are that may be associated with and/or calibrated or tuned to the user; notably, such parameters may be stored in memory in the portable monitoring device. Different or multiple equations may be employed to account for different swimming stroke types.

Calorie burn may also be calculated roughly as a function of one or more of the following variables: stroke type, lap count, and swimming duration.

Where the portable monitoring device determines or is instructed that the user is bicycling, calorie burn may be calculated, estimated and/or determined by:

$$\text{cal\_bike}=(A+B*\text{cadence})*\text{time},$$

where cadence is the number of foot pedal rotations of the user over a time epoch, time is the length of time under consideration, and (A,B) are that may be associated with and/or calibrated or tuned to the user; notably, such parameters may be stored in memory in the portable monitoring device.

Augmentation Using Altitude Data

In other embodiments, the portable monitoring device augments and/or adjusts the estimation, calculation and/or determination of calorie consumption, burn and/or expenditure, using or based on altitude related information (for example, from an altimeter disposed on the portable monitoring

device). In these embodiments, the portable monitoring device may employ the speed-based calorie consumption, burn and/or expenditure techniques described herein in conjunction with altimeter or altitude (or change in altitude) related information. For example, in the MET-table based approach disclosed herein, the resulting calorie output may be expressed, characterized, determined, calculated and/or estimated as:

$$\text{cal}=(MET(\text{speed})*k1(\Delta H\text{-}S))*\text{time}*BMR,$$

or

$$\text{cal}=(MET(\text{speed})+k2(\text{speed},\Delta H\text{-}S))*\text{time}*BMR,$$

or

$$\text{cal}=(MET(\text{speed})*k1(\Delta H\text{-}S)+k2(\text{speed},\Delta H\text{-}S))*\text{time}*BMR,$$

where MET(speed) is the nominal calorie output over flat land as a function of speed, k1(ΔH-S) and k2(speed, ΔH-S) are a scaling and offset term that are functions of ΔH-S (i.e., the change in elevation per step) and/or speed, and time is the length of time under consideration. k1(ΔH-S) and k2(speed, ΔH-S) are parameters or functions that may be tuned to the user.

In another embodiment, calorie burn may be expressed or characterized as (and determined, calculated and/or estimated using) a linear function of speed and as a function of ΔH-S:

$$\text{cal}=((A+B*\text{speed})*k1(\Delta H\text{-}S)+k2(\text{speed},\Delta H\text{-}S))*\text{time}*BMR,$$

where (A,B) are parameters are that may be associated with and/or calibrated or tuned to the user, and time is the length of time under consideration; notably, such parameters may be stored in memory in the portable monitoring device.

In the preceding equations, the terms dependent on ΔH-S may equivalently be written as functions of the surface slope or grade by substituting the distance traveled per step. Notably, this may be a more natural expression when speed is calculated by means other than step counting as in, for instance, foot-mounted speed and distance tracking or GPS:

$$\text{cal}=(MET(\text{speed})*k1(\text{slope})+k2(\text{speed},\text{slope}))*\text{time}*BMR,$$

or

$$\text{cal}=((A+B*\text{speed})*k1(\text{slope})+k2(\text{speed},\text{slope}))*\text{time}*BMR.$$

The preceding two equations are equivalent to adjusting the calorie burn estimate obtained on a level surface, adjusted with an additive and/or multiplicative factor that is dependent on user slope and/or speed.

Furthermore, step length may be written as a function of step frequency, ΔH-S, or characteristics of the user acceleration (or combinations therein). For instance,

$$\text{step length}=A+B*\text{step frequency}+C*\text{variance of acceleration}+D*\Delta H\text{-}S,$$

where (A,B,C,D) are parameters. These parameters may be tailored to an individual based on the calibration methods described above or equivalent techniques.

In one embodiment, the altitude correction to energy expenditure may be an additive term calculated as:

$$d\text{cal}=k*\text{speed}*\text{grade}*BMR.$$

This equation naturally accounts for reduced energy expenditure when going downhill (i.e., grade<0) and increased energy expenditure when going uphill (i.e., grade>0). However, energy expenditure may also increase when going down steep grades in excess of roughly 0.10. In such cases, the altitude correction term may be adapted with an offset and different multiplication constant k. Indeed, in a variety of scenarios, the correction term may be adapted with offsets and multiplication constants that are appropriate for the given activity state and/or mode (e.g., running, walking, jumping, etc.).

Certain numerical simplifications may be used to reduce the number of computations performed on the portable monitoring device. For instance, by observing that the speed over a time epoch may be estimated as the number of user steps multiplied by the user's step length and the surface grade may be approximated as the change in user elevation divided by the change in user horizontal distance, the preceding additive adjustment term may be calculated as:

$$d\text{cal}=k'*\text{steps}*\Delta H\text{-}S*BMR.$$

Notably, all such mathematical manipulations of the preceding methods that yield identical or substantially equivalent results are considered within the scope of the present inventions.

Notably, in one embodiment, if ΔH-S exceeds a predetermined threshold, the processing circuitry may determine that the user is traversing stairs, in which case, specific stair estimation algorithms may be employed. With reference to FIG. **4**R, the processing circuitry may employ an embodiment in which upstairs walking and running are given specific calorie burn algorithms based on ΔH-S. Downstairs logic may be incorporated therein. Likewise, specific equations and/or logic may be employed for different grade hills, both upwards and downwards in accordance with the preceding linear equations, or alternate nonlinear equations and means (e.g., lookup tables, polynomials, transcendentals, interpolations, neural nets, maximum likelihood estimates, expected value estimates, etc.).

For example, in the context of running/walking on stairs, hills or ground having a grade of greater than about 2-3%, the algorithm, determination or calculation of the energy and/or calorie "burn" may employ such considerations or factors as number of stair and/or hill steps, surface grade, ascent/descent distance on stairs and/or hill, pace thereof, ascent/descent on elevators. Indeed, in the context of swimming, the algorithm, determination or calculation of the energy and/or calorie "burn" may employ such considerations or factors as number of strokes, time between strokes and similar metrics (variance of stroke time, mean stroke time, etc.), depth underwater, stroke type, strokes per lap, lap time, pace and/or distance. Further, in the context of using a bicycle, wheelchair, skateboard, skis, snowboard, ladder, etc., the algorithm, determination or calculation of the energy and/or calorie "burn" may employ such considerations or factors as ascent/descent distance traversed, number of additional calories expended, time of a downward "run" or upward "climb", number of calories expended, number of pedal rotations, arm or wheel rotation, the grade of the surface, pushes, kicks and/or steps.

As intimated above, data which is representative of the altitude and/or changes in altitude and data which is representative of the motion of the user may also be used to determine and/or classify other activity-related metrics such as, for example, user steps, distance and pace (FIG. **4**E). For example, user distance may be calculated as the number of user steps multiplied by the user's step length, which in turn

is calculated as a function of ΔH-S and/or the change in altitude over time ("ΔH-t"). Notably, other activity-related metrics may be determined by the processing circuitry, including, for example, (i) in the context of running/walking on level or substantially level ground, number of steps, also broken down as walking or running, distance traveled and/or pace (ii) in the context of running/walking on stairs, hills or ground having a grade of greater than about 3%, number of stair and/or hill steps, which may be categorized or broken down, correlated or organized/arranged according to, for example, the speed, pace and/or activity state of the user (for example, as walking, jogging or running), number of flights of stairs, ascent/descent distance on stairs and/or hills, pace, ascent/descent on elevators and/or escalators, surface grade, and/or number of calories expended by walking/jogging/running on stairs and/or hills as well as quantify/compare the additional calories burnt from stairs/hills over level ground.

In another embodiment, data from one or more physiological sensors may be employed, alone or in combination with data of the motion sensor(s) and altitude sensor(s), to determine or assess the user state. (See, for example, FIGS. **4**F and **4**O). As discussed in more detail below, physiological sensor(s) determine, sense, detect, assess and/or obtain information which is representative of physiological condition and/or information of the user (for example, blood pressure, pulse rate, blood sugar and the waveform shape corresponding to the heart beat). Such an embodiment may, among other things, enhance the accuracy of identifying the user state and/or improve the confidence of the correctness/accuracy of the identified user state.

The data from the altitude, motion and physiological sensors may also be used to determine, calculate, estimate, improve and/or classify other activity-related metrics such as, for example, user speed and distance (FIG. **4**G). Indeed, the same sensor combinations may also be used to determine, identify and/or classify the user state in order to select the appropriate activity quantification algorithm—see, for example, FIG. **4**H wherein calorie burn corresponding to level ground, up/down hill, up/down stairs walking or running. Likewise this set or subset of sensors may be used to estimate and/or calculate the probability of each user state, which may then be used to select the activity quantification algorithm with maximum likelihood (see FIG. **4**I or **4**M) or merged together to provide the expected value (see FIG. **4**J or **4**N). A number of methods may be devised to implement each of the embodiments shown in FIGS. **4**A-**4**J and **4**M-**4**R, including but not limited to, iterative and batch algorithms that use ad hoc logic, statistical filtering and classification techniques, neural networks, k-means classifiers, and decision trees. Such conventional techniques or methods may be implemented in the present inventions or adaptively modified as they are used in the invention. As such, these embodiments of the inventions are merely exemplary and are not intended to be exhaustive or limiting of the inventions to, for example, the precise forms, techniques, flow, and/or configurations disclosed.

In one embodiment, the processing circuitry may evaluate the output of the altitude sensor to determine, calculate and/or estimate the activity state of the user by evaluating the altitude sensor data based on algorithms or processes based on the flowchart of FIG. **4**K. With reference to FIG. **4**K, in one embodiment, the processing circuitry determines the type of activity by evaluating the change in altitude of the user on a change in height or altitude per step basis ("ΔH-S") or the use of an elevator by a sustained rate of height change pre time period (for example, per second) ("ΔH-t") in the absence of steps. The change in height or altitude per step and change in

height or altitude per second are evaluated against a plurality of thresholds and/or ranges to determine whether the user is, for example, moving (for example, running or walking) on level ground, on an escalator or in an elevator, traversing stairs and/or traversing a hill or the like. In one embodiment, Threshold **1**, Threshold **2**, Threshold **3** and Threshold **4** have the relationship Threshold **1**>Threshold **2**>Threshold **3**>Threshold **4** wherein the process seeks to detect and identify the causes of increases in user altitude. In other embodiments, the flow may be modified to detect and classify decreases or both increases and decreases in user altitude. Thus, in these embodiments, the processing circuitry employs data from the motion sensor to assess the user state based on data from the altitude sensor. An exemplary implementation is illustrated in FIG. **6**.

Notably, for the avoidance of doubt, the inventions are not limited to processes and/or algorithms implemented in accordance with the flow charts of FIGS. **4**A-**4**R. Such flow charts are merely exemplary. The present inventions may also implement batch processing algorithms (as opposed to the real-time algorithm), the use of probabilistic classification and estimation methods such as, for example, bayesian networks, Kalman filters, particle filters, unscented Kalman filters (aka sigma point Kalman filters), EM algorithm and Metropolis-Hastings algorithm, Gibbs sampling, Wiener filter, alpha-beta filter, or artificial neural networks. All permutations and combinations of the physiological conditions are intended to fall within the scope of the present inventions.

In another embodiment, the portable monitoring device of the present inventions includes one or more physiological sensors to further assess the activity state of the user. For example, with reference to FIGS. **1**B and **7**, the physiological sensor(s) may provide data which is representative of the physiological condition of the user. The processing circuitry may correlate the data from the physiological sensor(s) with the (i) data which is representative of the altitude and/or changes in altitude and (ii) data which is representative of the motion of the user, to determine, estimate and/or calculate energy and/or calorie "burn" of the user. For example, an apparent increase in altitude coupled with the expected number of human steps and a correspondingly increase in heart rate enables the processing circuitry (and techniques implemented thereby) to assess such data and more accurately correlate the activity to a user state—for example, distinguish stair steps from a measurement artifact.

In one embodiment, the processing circuitry may employ a decision-tree based technique/algorithm to interpret or assess changes in altitude, motion and physiological condition of the user. The decision tree based technique/algorithm may employ the flow chart of FIG. **4**L in which, as another embodiment, the processing circuitry determines the type of activity by evaluating the change in altitude of the user on a change in height per step basis ("ΔH-S") or the use of an elevator by a sustained rate of height change per temporal period (for example, seconds) ("ΔH-t") in the absence of steps in conjunction with heart rate ("HR"). The change in height per step, change in height per second, and heart rate are evaluated against a plurality of thresholds and/or ranges to determine whether the user is, for example, moving (for example, running or walking) on level ground, on an escalator or in an elevator, traversing stairs and/or traversing a hill or the like. In one embodiment, Threshold **1**, Threshold **2**, Threshold **3** and Threshold **4** have the relationship Threshold **1**>Threshold **2**>Threshold **3**>Threshold **4**. Thus, in this embodiment, the processing circuitry employs data from the motion sensor to assess the user state based on data from the altitude sensor and physiological sensor. Similar techniques/

algorithms may employ the flow of FIG. **4**L and a similar flowchart based on thresholds in relation to other certain physiological conditions including blood pressure, pulse rate, blood sugar and the waveform shape corresponding to the heart beat.

In one embodiment, rather than making a firm "decision" based on thresholds, the processing circuitry may employ the sensor data individually or in combination in a statistical or ad hoc framework to provide probabilities for each potential user state. Such techniques may provide a higher degree of confidence in connection with determining the user state.

The processing circuitry may employ filtering methods and state estimation to mitigate, address and/or alleviate noise (for example, random noise) and outliers present or inherent in the altimeter data. For example, in a preferred embodiment, several parameters of interest may be described in state-space notation:

$$x(t)=[H(t)dH(t)]^T,$$

where x is the state vector, H is altitude or height, and dH is the first derivative of H with respect to time.

In this notation, dH(t) is similar or equivalent to the parameter ΔH-t described previously. Note that these parameters are expressed as functions of time.

In another preferred embodiment, several parameters of interest may be described in an alternate state space:

$$x(\text{step})=[H(\text{step})dH(\text{step})]^T,$$

where x is the state vector, H is the altitude, and dH is the first derivative of H now expressed as functions of step, where the implicit relationship on time for step is omitted for notational simplicity.

Notably, dH(step) is similar or equivalent to the parameter ΔH-S described previously. The time-space and step-space representations may be employed together or separately in one or more estimation techniques. Indeed, when used separately, many methods may be used to estimate the derivative that is not covered in the representation. For example, when only the time-space representation is used, the parameter dH(step) may be estimated as:

$$dH_{EST}(\text{step})=(H_{EST}(t)-H_{EST}(t-dT))/(\text{step}(t)-\text{step}(t-dT)),$$

where dT is a time interval, step(t) is the step count at time t, and the EST subscript denotes an estimate.

Similarly, when the step-space representation is used, the parameter dH(t) may be estimated as:

$$dH_{EST}(t)=(H_{EST}(\text{step}(t))-H_{EST}(\text{step}(t)-\text{step}(t-dT)))/(t-dT),$$

where dT is a time interval.

Given the state vector x, many models may be employed to regularize the estimates of x in a model-based observer such as a Luenberger observer, Kalman filter, least squares estimator, recursive least squares estimator, intermediate multiple model filter (IMM), extended Kalman filter, particle filter, unscented Kalman filter (aka sigma point filter), etc. In a time-space representation, the altitude of the user may be described by a constant velocity model:

$$x(t+dT)=Fx(t)+w,$$

$$F=\begin{bmatrix}1 & dT\\ 0 & 1\end{bmatrix},$$

where dT is a time interval and w is process noise.

In a step-space representation, the altitude of the user may be described by a constant velocity model:

$$x(step+dStep)=Fx(step)+w,$$

$$F=\begin{bmatrix}1 & dStep\\ 0 & 1\end{bmatrix},$$

where dStep=x(step(t+dT))−x(step(t)) and w is process noise.

Note that in both models, a constant altitude may be obtained by fixing dH=0. One or more constant altitude models and constant velocity models may be desirable in a multiple model filter. In certain cases, it may be useful to use a multiple model filter such as an IMM or multiple hypothesis filter in order to obtain fast estimate convergence during transitions that are not constant velocity. Process noise in a constant velocity model may be tuned through historical analysis of pressure measurements while the user is not moving.

The model-based approach permits the prediction of future altitude measurements as:

$$x_{PRED}(t+dT)=CFx_{EST}(t),$$

$$x_{PRED}(\text{step}+d\text{Step})=CFx_{EST}(\text{step}),$$

$$C=[1\ 0],$$

for both models.

Defining z=H+v to be a noise corrupted measurement of altitude, a residual may be calculated as:

$$\text{resid}=z-X_{PRED}$$

which allows the statistical rejection of outliers against known measurement and process noise statistics through, for instance, hypothesis testing. Other outlier rejection and step offset compensation methods may be employed including those apparent to those skilled in the art.

By setting C=[1 0], we have implicitly assumed that the measurements obtained are altitude measurements. However, the present inventions are not limited to such, nor are they limited to the set of linear models as described thus far. For instance, a raw measurement may be barometric pressure and it may relate to altitude by the function H=C(pressure), where C(•) is a standard, nonlinear barometric equation. In such cases, the system may be linearized to work within the framework of a linear estimator (e.g., extended Kalman filter) or a nonlinear estimator may be used (e.g., particle filter).

The processing circuitry may employ other estimation and filtering methods. For instance, in one embodiment, H may be estimated with a median, moving average, exponentially weight moving average, low pass filter, etc. dH(step) and dH(t) may likewise be estimated in a variety of ways involving finite differencing with or without smoothing, etc. All such techniques are intended to fall within the scope of the present inventions.

The processing circuitry may employ state machine logic to determine, estimate and/or calculate a change in altitude. FIGS. **8**A-**8**F illustrates several embodiments of exemplary state machine logic for calculating human-derived altitude. In some embodiments for calculating human-derived altitude (FIGS. **8**A-**8**C), data of the motion sensor is used to determine if the user is currently walking/running as well as if the user recently executed a step. This may be achieved, for instance, with a pedometer. For example, FIG. **8**A depicts an embodiment where, although data of the motion sensor is used to

determine if the user is currently walking/running, the sampling of the altitude sensor (to acquire data which is representative of the altitude and/or change in altitude of the user) is performed independent of the data from the motion sensor. In contrast, FIG. **8**B depicts an alternate embodiment where the sampling rate of the altitude sensor is calculated as a function of the data from the motion sensor. In this case, the sampling frequency F_{ALT} is a function of the user's step frequency. FIG. **8**C depicts an embodiment where sampling of the altitude sensor is triggered from events detected by the motion sensor. In this exemplary embodiment, the event is detection of a step by the user. Although not depicted in FIG. **8**C, altitude measurements may be obtained following some delay after the detection of the triggering event. This may be useful in systems where a change in measured altitude occur after some latency, as in cases where a barometric pressure sensor is mounted in a sealed enclosure and samples the external atmospheric pressure through a vent. Altitude sensor measurements may also be triggered by events related to the stop of motion as in, for instance, when the user stops walking for several seconds.

Notably, in other embodiments, characteristics of the motion sensor are used to determine if the user is currently moving as well as if the user recently executed a motion event. (See, for example, FIGS. **8**D-**8**F). Thus, in these embodiments for calculating human-derived altitude (FIGS. **8**A-**8**C), data of the motion sensor is used to determine if the user is currently walking/running as well as where the user recently (for example, within a previous predetermined amount of time) executed a motion event.

FIG. **8**G provides exemplary state machine logic that may be used to accumulate human-derived elevation gain. In this exemplary embodiment, the state machine logic employs a plurality of thresholds to indicate the start, stop, and continuation of sustained elevation changes. These thresholds are denoted by T_{ij}, $i\in\{A, B, C, D\}$, $j\in\{1, 2, 3, 4\}$; however, these are intended as examples and in other embodiments of the inventions, there may be differing numbers and combinations of thresholds. Elevation gain is accumulated when the current estimate of elevation H_{EST} exceeds a reference H_{REF} by at least the amount given by the threshold, as well as when ΔH-S and ΔH-t are within certain thresholds. Appropriate settings of the thresholds may provide "hysteresis" in the accumulation of elevation gain and likewise restrict impossible or improbable conditions. For instance, setting T_{A2}=1 ft/step and T_{A3}=0 ft/step restrict user elevation gains to fall within those prescribed by typical staircases. A typical stair step is 6 inches and a user walking up two stairs a time may cover 1 ft per step.

As mentioned above, in one embodiment, the processing circuitry computes, estimates and/or determines a number of stair steps traversed by the user (for example, the number of upward stair steps). For example, with reference to FIG. **8**H, in one exemplary embodiment, when ΔH-S and ΔH-t first meet a first criteria, the processing circuitry determines, calculates and/or estimates an onset of the first step of the stair sequence. An exemplary value for the threshold T_{S2} is 5 inches, which is a low riser height for a staircase. Stair steps are accumulated thereafter until ΔH-S and ΔH-t do not meet a second criteria.

Notably, the processing circuitry may determine, calculate and/or estimate a first step in a stair sequence using any technique now known or later developed. For example, the processing circuitry may employ the following: One or both of the derivatives (ΔH-S and ΔH-t) may be back-propagated to their intersection with a relatively flat region of the measured and/or filtered altitude curve. Indeed, the first step may be identified as the changepoint between two intersecting lines in either the time or step-space representations (or both) and well-known estimation techniques may be employed.

The method described here may be adapted to calculate the number of downward stair steps, and/or the altitude gain/loss from upward/downward stair steps, and/or the calorie expenditure from the upward/downward traversal of stairs and/or the number of stair flights traversed upward/downward and/or the number of stair flight/step equivalents traversed upward/downward (e.g., by dividing the altitude gain/loss by a nominal stair flight/step height). All combinations and permutations are intended to fall within the scope of the present inventions. In one embodiment, the portable monitoring device may be used to determine, calculate and/or estimate the step rise and/or step tread on a staircase.

In lieu of or in combination with stair steps, altitude gain, etc., the portable monitoring device may also calculate metrics (for example, motivational metrics) and/or calculate the state of avatars (for example, a digital "pet", a graphical representation of the user or his/her alter ego, a game character, or physical object that glows and/or changes physical configuration) that are partially or completely determined by user altitude changes. For example, the device may calculate (and, in addition, may display to the user) "elevation points", where one elevation point is representative of a change in altitude, a stair, and/or a flight of stairs (for example, one elevation point is equal to approximately ten feet, or one flight of stairs). A user may then be motivated to increase an elevation point score or total by, for example, traversing more stairs, flights of stairs and/or hills. Moreover, the device may also maintain the state of a virtual avatar, for example, a flower, whose growth and/or health is related to user altitude changes, or a building, whose size and/or growth is related to user altitude changes, or an entity that morphs between states that are indicative of increased or decreased elevation gains such as a stair case, ladder, hill, or mountain, or specific landmarks like the Eiffel Tower, Mt. Everest, and the Moon. Indeed, all games and/or avatars that are controlled in part or wholly by changes in altitude sensor data are intended as embodiments of the present inventions.

In other aspects of the present inventions, the altitude changes may be combined, integrated and/or fused with other information such as user speed, step frequency, surface grade, stair steps, calorie burn, energy expenditure, heart rate, etc. to obtain more general "activity points", where, for example, activity points may be described as:

$$AP=k1*MET+k2*\Delta H+k3*(\mathrm{HR}-\mathrm{HR}_0),$$

where k1, k2, and k3 are parameters, MET are metabolic equivalent units expended, HR is the user's heart rate and HR_0 is a nominal at-rest heart rate.

This equation is provided merely for illustration. Indeed, all relationships that describe activity points and/or "grades" and/or activity metrics that are not inherently physical quantities (e.g., calorie burn) and/or avatar states as an integrated, combined and/or fused output from one or more of user motion data, user physiological data, user elevation data, and/or user location data are simply embodiments of the present inventions. Likewise, all relationships that describe elevation points, and/or "grades" and/or metrics that are not inherently physical quantities (e.g., elevation gain) and/or avatar states as an output from either altitude data alone or in combination with user motion data, user physiological data, and/or user location data are simply embodiments of the present inventions. In some embodiments, the motivational metrics and/or avatars may be computed and/or displayed on the portable monitoring device. In other embodiments, the

motivational metrics and/or avatars may be computed and/or displayed on other media (e.g., www.fitbit.com) using data from the portable monitoring device. In yet other embodiments, the motivational metrics and/or avatars may be computed and/or displayed on both the portable monitoring device and other media.

Notably, in one embodiment, the processing circuitry may adjust certain thresholds (for example, thresholds employed in conjunction with the techniques described herein) dynamically according to a variety of parameters to mitigate noise and drift from appearing in the output accumulated elevation gain. For example, such parameters may be based on surface conditions, weather, temperature, humidity, user motion, and physiological data from the user. Examples include the surface grade, user speed, user step frequency, user energy expenditure rate, user activity state (e.g., walking versus running versus jumping), ΔH-S, ΔH-t, weather conditions (e.g., incoming storm, wind, rain), the rate of change in barometric pressure while the user is not moving, the rate of change of temperature change, variation in the barometric pressure signal and/or altitude measurement (e.g., random noise), motion sensor data energy, motion sensor data variation, and/or heart rate.

In an exemplary embodiment, the thresholds required to accumulate an elevation gain follow a decreasing function with respect to surface grade, such that shallower grades require larger altitude gains and steeper grades permit smaller altitude gains. Furthermore in this regard, different functions may be used for walking and running such that shallower grades have lower thresholds for running than they do in comparison to walking. This is motivated by the fact that humans selectively perceive surface grades according to how fast they move on the surface. That is, shallower grades are easier to detect when the user is running rather than walking. Similar effects may be achieved by setting the thresholds as a function of surface grade and user speed or surface grade and user step frequency. Indeed, all possible combinations of the previously mentioned parameters may be used. Note that certain surface grades may be rejected from accumulation by setting their respective thresholds to infinity. In one embodiment, elevation gains and/or losses are only permitted for grades in excess of ±2%. The thresholds may also be adapted according to the drift and/or noise present on the altitude sensor while the user is not moving. In this way, the algorithm may adjust for changing weather conditions as observed by a barometric pressure sensor.

Surface grade may be expressed as the elevation change over a horizontal distance:

$$g=\Delta H/d.$$

When d is not directly measured (as in the case of GPS tracking), it may be calculated as:

$$d=\mathrm{sqrt}(d_s^2+\Delta H^2),$$

where d_s is the distance traveled overland by the user.

For typical walking and running surface grades, it is sufficient to approximate $d=d_s$. Other numerical approximations exist and are apparent to one skilled in the art. The overland distance may be measured by any of a variety of methods, some of which were described above. They include use of a pedometer function or foot-mounted distance tracking. In other embodiments, the inventions may have functionality that determines the elevation change and/or slope between two points through, for instance, the use of GPS with an altimeter.

Notably, FIGS. **8**A-**8**H are illustrative and are not intended to limit the implementation of the present inventions. For the avoidance of doubt, the thresholds depicted in the figures may be implemented on the measurements and/or estimates of altitude. The threshold logic may also be implemented over a sequence of points or over a time interval or both. In certain circumstances, it may not be useful or desirable to include all of the threshold parameters described. For instance, it may not always be useful to include thresholds against ΔH-S or ΔH-t. The thresholds may also be supplanted with probabilistic functions evaluated jointly or conditionally over (ΔH, ΔH-S, ΔH-t) or individually over some or all of the same parameters. The portable monitoring device may also employ a variety of timers and event counters to block certain calculation steps when, for instance, significant jumps in elevation are seen, noise increases, or outliers are encountered. Timers and/or counters may also be employed to reset the state of the algorithm (for example, state=0) and/or filter when a downward or upward accumulation event has not occurred within a certain time interval or number of iterations. The reference altitude H_{REF} may also be refined over time or reinitialized according to certain criteria through a variety of filtering and estimation techniques. The methods described herein may be adapted to calculate elevation loss, or to calculate elevation gains/losses distinguished by surface grade and/or stair conditions.

The sampling rate of the sensors of the portable monitoring device may be predetermined or fixed. In one embodiment, the sampling rate is programmable or controllable. For example, in one embodiment, the portable monitoring device may control and/or determine the sampling rate of the sensors based on considerations of electrical power consumption and the rate thereof. In this regard, the portable monitoring device may employ electrical power saving circuitry and/or techniques to control and/or determine the sampling rate of the sensors.

In one embodiment, the sampling frequency of the altitude sensor (F_{ALT}) may be controlled, determined and/or calculated based on data from the motion sensor. For example, with reference to FIG. **9**A, in one embodiment, if the motion of the user does not exceed a threshold within a time period (for example, a predetermined or programmable time period), the altitude sensor may be placed into a mode that does not sample (for example, a low power mode), or F_{ALT} may be reduced or decreased. Subsequently, if the motion exceeds a threshold, for example, for a predetermined or minimum time duration, F_{ALT} may be increased.

Notably, "motion" in this context is meant generally and includes features derived from raw motion sensor data. Examples would be the signal energy, variance, range, etc. The mapping of motion to F_{ALT} may be a continuous function or discrete settings. In the case of one or more discrete settings (e.g., sampling modes), the features used to transition between modes are not necessarily the same, nor are the thresholds and other parameters dictating the transitions.

FIGS. **9**B and **9**C depict other exemplary embodiments in which the sampling mode or frequency of the altitude sensor is determined by the output of a pedometer. Here again, the portable monitoring device senses the motion of the user and, based thereon, controls and/or determines the sampling rate of the altitude sensor. In this way, the portable monitoring device manages or controls the electrical power consumption, and the rate thereof.

FIG. **9**D illustrates another embodiment where altitude sensor readings are triggered from step events detected by a pedometer, or a maximum time T between samples (whichever occurs first). Although not depicted in FIG. **9**D, altitude sensor readings may be scheduled to occur after a delay from the step event. The step-space representation and models

described above are suited to this type of sampling. Setting T=∞ reduces to the case where altitude readings are only generated through triggering from a pedometer.

In another embodiment, the altitude sensor may be read or its sampling mode/frequency may be controlled or set according to peaks and/or other morphological features derived from the motion sensor. For example, the sampling rate of the altimeter may be set higher and/or its measurement settings may be adjusted (e.g., to a finer setting) if the motion sensor provides a signal that is indicative of the user losing balance and/or about to fall or falling (e.g., free fall). Similarly, the sampling settings may be adjusted to capture fast transient elevation changes that may be experienced during jumping with one's legs or by other means (e.g., skateboard, skis and snowboard, pole vaulting, and the like—the settings being determined by data from the motion sensor that is indicative of the activity).

The aforementioned discussions in connection with FIGS. **8**A-**8**H and **9**A-**9**D may be implemented in conjunction with any of technique to calculate calorie burn, including the techniques described and illustrated herein. All permutations and combinations of (i) calculating elevation or altitude change and (ii) altitude sampling techniques, and (iii) techniques to calculate calorie burn are intended to fall within the scope of the present inventions. Moreover, as stated above, the inventions are not limited to processes and/or algorithms implemented in accordance with the flow charts of FIGS. **8**A-**8**H and **9**A-**9**D. Such flow charts are merely exemplary. The present inventions may also implement batch processing algorithms (as opposed to the real-time algorithm), the use of probabilistic classification and estimation methods such as, for example, bayesian networks, Kalman filters, EM algorithm and Metropolis-Hastings algorithm, or artificial neural networks.

The portable monitoring device of the present inventions may also include a user interface to facilitate communication with the user. (See, for example, FIG. **1**C) The user interface may include one or more displays, one or more of a speaker, microphone, vibramotor, and/or an input mechanism. (See, for example, FIGS. **10**A-**10**F). Indeed, any manner of or mechanism for outputting and/or inputting of data and/or commands are intended to fall within the scope of the present inventions.

In one embodiment, the portable monitoring device includes one or more mode sensors to input, detect and/or determine a mode of movement by the user. (See, for example, FIG. **1**D). For example, the user may input, detect and/or determine that the user is in a wheelchair, on a ladder, skate board, skis, snowboard and/or a bicycle. In response thereto, the processing circuitry may correlate and/or employ the data from the mode sensor(s) with the (i) data which is representative of the altitude and/or changes in altitude and (ii) data which is representative of the motion of the user, to determine, estimate, and/or calculate energy and/or calorie "burn" of the user. For example, where the user is on a bicycle, the processing circuitry may determine or calculate energy and/or calorie "burn" of the user using the (i) data which is representative of the altitude and/or changes in altitude and (ii) data which is representative of the motion of the user. Notably, the mode sensor may be responsive to a user input or detected mode of movement.

In one embodiment, FIG. **11**A depicts the processing flow for the use of the mode sensor in selecting the appropriate algorithm for determining calorie "burn" of the user. Similarly, FIG. **11**B depicts the processing flow for the use of the mode sensor in selecting the appropriate activity-tracking algorithms for the user based on the mode of motion or movement.

There are many mechanisms and techniques by which the mode sensor(s) may be implemented. One embodiment employs buttons and a feedback mechanism such as a graphical display, flashing lights, haptic device, piezoelectric buzzer, vibramotor, and/or speaker (all, for example, elements of the user interface) to navigate a menu system to select different modes. Another embodiment uses one or more of the motion sensors to recognize user gestures to select and deselect certain modes. In yet another embodiment, the portable monitoring device may include a user interface having an input device (for example, one or more buttons) and/or sensors that mate with specialized housings for each mode. For example, placing the device onto a designated wheelchair mounting device could push a button on the device to select a wheelchair mode. In another embodiment, device may be placed near a designated RF beacon that is affixed to a bicycle spoke, in which case the device would execute bicycle mode functionality. Other implementations may use, for example, RFIDs, magnetic sensors, LEDs and photodetectors, piezoelectric strip/material and/or strain gauges, to detect the presence of the specialized mounting apparatus. In yet another embodiment, the motion sensor(s), altitude sensor(s), and physiological sensor(s) are employed to recognize user activity and automatically select the mode.

Notably, the mode may be selected and/or determined from a plurality of pre-programmed or predetermined modes (for example, during manufacture). Such pre-programmed or predetermined modes may be stored in memory in the processing circuitry of the device. In addition thereto, or in lieu thereof, the modes may be user defined (after manufacture—for example, in situ or during operation) and programmed into or onto the device by the user at a later time and corresponding activity quantification algorithms may be adaptively "trained" or "taught" by the user.

In yet another embodiment, the portable monitoring device includes the motion sensor, altitude sensor, physiological sensor and mode sensor. Indeed, all permutations and combinations of sensors, whether in conjunction with a user interface or not, may be employed or implemented in a portable monitoring device according to the present inventions. All such combinations and permutations are intended to fall with in the scope of the present inventions.

The portable monitoring device may include transmitter circuitry to communicate energy and/or calorie "burn" of the user to, for example, an external user interface, the Internet, social or media site (for example, Fitbit or Facebook) and/or computing system. (See, for example, FIG. **1**F). The portable monitoring device may also output raw or pseudo-raw sensor data as well as a correlation thereof (see, for example, FIG. **6**). Indeed, the portable monitoring device may output the other activity-related metrics, including, for example, (i) in the context of running/walking on level, substantially level, or relatively level ground, (a) number of steps, which may be categorized according to the number of steps associated with a user state, for example, walking, jogging and/or running, (b) distance traveled and/or (c) pace, (ii) in the context of running/walking on stairs, hills or ground having a grade of greater than, for example, about 3%, (a) number of stair and/or hill steps, which may be categorized, correlated or organized/arranged according to, for example, the speed, pace and/or activity state of the user (for example, the number of stair and/or hill steps pertaining to walking, jogging and/or running), (b) number of flights of stairs, (c) ascent/descent distance on stairs and/or hills, (d) pace, (e) ascent/descent on

elevators, (f) number of calories expended by walking/jogging/running on stairs and/or hills and/or (g) quantify/compare the additional calories expended or burnt from stairs/hills relative to, versus or over level ground, (iii) in the context of swimming, number of strokes, time between strokes, leg kicks and similar metrics (variance of stroke time, mean stroke time, etc.), depth underwater, strokes per lap, lap time, pace and/or distance, (iv) in the context of using a bicycle, wheelchair, skateboard, skis, snowboard, ladder, etc., (a) ascent/descent distance traversed, (b) number of additional calories expended, (c) time of a downward "run" or upward "climb", (d) number of calories expended, (e) number of pedal rotations, (f) arm or wheel rotation, (g) the grade of the surface, (h) pushes, kicks and/or steps. This list of activities (if applicable to the particular embodiment) is merely exemplary and is not intended to be exhaustive or limiting of the inventions to, for example, the precise forms, techniques, flow, and/or configurations disclosed.

The portable monitoring device of the present inventions may include communication circuitry which implements or employs any form of communications (for example, wireless, optical, or wired) and/or protocol (for example, standard or proprietary) now known or later developed, all forms of communications and protocols are intended to fall within the scope of the present inventions (for example, Bluetooth, ANT, WLAN, Wi-Fi, power-line networking, all types and forms of Internet based communications, and/or SMS); all forms of communications and protocols are intended to fall within the scope of the present inventions.

The portable monitoring device may include receiver circuitry to more fully communicate with the user and/or external circuitry. (See, for example, FIG. **1**G). For example, the portable monitoring device may receive external data or commands regarding exercise time, energy use and/or calorie "burn", and milestones, for example, from the internet, social or media site (for example, Fitbit or Facebook) and/or computing system; all forms of receiver circuitry and receiving protocols are intended to fall within the scope of the present inventions.

Again, all permutations and combinations of sensors, user interface, transmitter circuitry and receiver circuitry, may be employed or implemented in a portable monitoring device according to the present inventions. (See, for example, FIGS. **1**A-**1**X). All such combinations and permutations are intended to fall with in the scope of the present inventions.

As such, the portable monitoring device of the present inventions may interface or communicate via any connectivity and protocol (for example, wired, wireless, electrical and/or optical and/or all types and forms of USB and/or removable memory). All communication mechanisms, techniques and architectures are intended to fall within the scope of the present inventions. Thus, the portable monitoring device may employ wired and/or wireless transmitter circuitry to communicate energy and/or calorie "burn" of the user to, for example, an external user interface, the internet, social or media site (for example, Fitbit or Facebook) and/or computing system. (See, for example, FIG. **1**F). As noted above, the portable monitoring device may also output raw or pseudo-raw sensor data as well as a correlation thereof (see, for example, FIG. **6**). Indeed, the portable monitoring device may be communicate energy and/or calorie "burn" or expenditure of the user (or such raw or pseudo-raw sensor data), for example, via transmitter circuitry, removable memory, wireless and/or wired (for example, electrical or optical) communication.

For example, in one embodiment, the portable monitoring device may be placed into a data transfer mode (for example, via engagement with a dock station, user input/instruction and/or proximity to base device) in which the display and/or suitable visual elements are used to transmit data, for example, to a base device (for example, a mobile phone, computer and/or internet portal device (for example, a router)). The base device may include one or more visual monitoring devices. In one embodiment, for example, the portable monitoring device may transmit data by switching on/off LCD segments, switching on/off individual or clusters of display pixels, and/or modulating the intensity and/or color of display pixels in the display of the user interface while base device (for example, mobile phone) monitors the display sequence with a camera and/or video camera. The data may be transmitted in any format now known or later developed including a suitable human readable format (for example, numbers and words), a binary sequence of bits (for example, bar code), or otherwise.

In another embodiment, the portable monitoring device includes or provides for bidirectional communication of the second portable monitoring device and/or a base device. In this embodiment, the second device controls a light source (e.g., camera phone flash, different colors on screen, pixels on/off) and the portable monitoring device analyzes and/or monitors the visual sequence with one or more visual sensors. This method of data transfer and communication may remove the need for additional wireless and/or wired hardware for transmitting data from the invention to another device, which itself may transfer the data to another service (e.g., www.fitbit.com).

As discussed herein, the display of the user interface may be the primary mechanism of displaying information to the user. That display may be placed into a mode to facilitate or execute an optical transfer communication. In other embodiments, the portable monitoring device may have specific visual sources that are only intended for data transfer, as well as the combination of both the primary user display and a data transfer display.

Notably, because alignment and placement of the portable monitoring device with a second device are important to the transfer process, either or both of the devices may have on-screen guides or instructions to aid alignment and placement. In one embodiment, the second device may show a template overlaid in its video display to help the user place the invention correctly relative to the second device. The portable monitoring device may have visual landmarks (e.g., borders, buttons, colors, and/or display elements) that enable the second device to visually track certain aspects of the portable monitoring device during data transfer. Visual tracking may also provide the user with alignment cues to improve placement (e.g., arrows). These same strategies may be employed by the portable monitoring device in cases of bidirectional communication.

The portable monitoring device may be equipped with one or more vibramotors, buzzers, and/or speakers with which to alert the user. For instance, the device may buzz or emit a sound to encourage the user to walk or move after observing a sedentary period of 30 minutes or more. The device may buzz or emit a sound in order to notify the user that the battery level is low. The device may buzz or emit a sound to act as a time-based alarm. Indeed, all manner of audible and/or haptic alerts are considered to be within the scope of the present inventions.

There are many inventions described and illustrated herein. While certain embodiments, features, attributes and advantages of the inventions have been described and illustrated, it should be understood that many others, as well as different and/or similar embodiments, features, attributes and advan-

tages of the present inventions, are apparent from the description and illustrations. As such, the above embodiments of the inventions are merely exemplary. They are not intended to be exhaustive or to limit the inventions to the precise forms, techniques, materials and/or configurations disclosed. Many modifications and variations are possible in light of this disclosure. It is to be understood that other embodiments may be utilized and operational changes may be made without departing from the scope of the present inventions. As such, the scope of the inventions is not limited solely to the description above because the description of the above embodiments has been presented for the purposes of illustration and description.

For example, in one embodiment, the portable monitoring device of the present invention includes an altitude sensor and motion sensor (and in certain embodiments other sensors such as one or more physiological sensors and/or one or more mode sensors). In this embodiment, the portable monitoring device, however, may not include processing circuitry to monitor, calculate, determine and/or detect energy and/or calorie "burn" due to physical activity of the user (for example, a human or non-human animal). In this embodiment, some or all of the monitoring, calculating, determining and/or detecting may be implemented "off-device" or external to the portable monitoring device. Here, the portable monitoring device may store and/or communicate (i) data which is representative of the altitude and/or changes in altitude of the user and/or (ii) data which is representative of motion of the user to external processing circuitry wherein such external processing circuitry may monitor, calculate, determine and/or detect energy and/or calorie "burn" due to physical activity of the user. (See, FIG. **12**A). Such external circuitry may implement the calculation processes and techniques in near real-time or after-the-fact. The data which is representative of the (i) altitude and/or changes in altitude of the user and/or (ii) motion of the user may be communicated to such external processing circuitry, for example, via transmitter circuitry (see FIG. **12**A), removable memory, electrical or optical communication (for example, hardwired communications via USB). Importantly, such an architecture/embodiment is intended to fall within the scope of the present inventions.

Moreover, the portable monitoring device of this embodiment (i.e., external processing circuitry) may include all permutations and combinations of sensors (for example, one or more physiological sensor(s) and/or mode sensor(s). For example, the portable monitoring device of the present inventions may include one or more altitude sensors (see, for example, FIGS. **1**A-**1**L); in other embodiments, the portable monitoring device does not include one or more an altitude sensors (see, for example, FIGS. **1**M-**1**X).

Notably, in one embodiment, the processing circuitry to monitor, calculate, determine and/or detect energy and/or calorie "burn" due to physical activity of the user may be distributed between resident circuitry and external circuitry. (See, FIG. **12**B). In this embodiment, circuitry disposed in the portable monitoring device may implement certain processes and algorithms and the external processing circuitry may implement other processes and algorithms wherein, the circuitry, in combination, monitors, calculates, determines and/or detects energy and/or calorie "burn" due to physical activity of the user.

In another embodiment, the exemplary portable monitoring devices may employ a MEMS altitude sensor. In this regard, the altitude sensor includes a MEMS pressure sensing structure to generate data which is representative of the altitude of the structure. For example, with reference to FIG. **13**, in one embodiment, the MEMS pressure sensing structure includes a multi-diaphragm structure wherein a first diaphragm **1** is more fully exposed to changes in the ambient environment relative to a second diaphragm which is less exposed to changes in the ambient environment due to a plurality of micro-pores **3**. The diaphragms **1** and **2** form a portion of a sealed chamber (for example, vacuum-sealed chamber). In one embodiment, the MEMS pressure sensing structure includes a pressure sensing element **5** to sense, sample, determine and/or obtain changes in pressure. Here, first diaphragm **1** is responsive to the environment with low pneumatic impedance so that there is effectively no latency. The second diaphragm is responsive to the environment through micro-pores that "delay" the rate of change of the pressure. This difference may deflect the bidirectional pressure sensing element **5** toward the side with lower pressure.

The sensor structure depicted in FIG. **13** is just one embodiment of one aspect of the inventions. The chambers on either side of the bi-directional sensing element need not be equal in size and either or both sealing diaphragms **1** and **2** may be omitted in some embodiments. For instance, the element producing the pneumatic impedance that delays pressure changes may effectively seal the chamber from contaminants because the element is a continuous polymer film.

In operation, the deflection in pressure sensing element **5** provides information which is representative of the change in altitude (due to changes in pressure). That is, the micro-pores "delay" the rate of pressure change caused by the second diaphragm in response to small changes in altitude relative to the first diaphragm (which has a low pneumatic impedance path to ambient). The deflection of in pressure sensing element **5** may be measured via changes in stress or strain in pressure sensing element **5**. In addition thereto, or in lieu thereof, the deflection may be measured by changes in capacitance or voltages of sensing plates (not illustrated).

Pressure equalization in a single-pore system can be expressed analytically for a simplified system. Assuming the inner chamber has volume V and is subject to a pressure difference of Δp which is much less than the absolute pressure p (i.e., Δp<<p) and that the inner chamber is exposed to the external environment through a hole of radius r and that the system has low Knudsen number, the mean velocity of gas flow at the orifice is

$$u = -\frac{r}{3\pi\eta}\Delta p,$$

where η is the viscosity of the gas (Roscoe 1949, Yu, et al. 1988).

The rate of change of the mass of gas in the chamber is

$$\dot{m} = -\rho\pi r^2 u,$$

where ρ is the density of the gas.

Finally, assuming the gas to be ideal and the system to be isovolumetric and isothermal, it can be shown that the rate of change of pressure in the chamber p_c is

$$\dot{p}_c = \left(\frac{\rho RT}{3\eta M}\right)\left(\frac{r^3}{V}\right)\Delta p,$$

where R is the universal gas constant, T is the temperature, and M is the molar mass of the gas.

As such, it can then be shown that the time constant for the system τ is

$$\tau = \left(\frac{3\eta M}{\rho RT}\right)\left(\frac{V}{r^3}\right).$$

For illustration, operating at standard temperature and pressure, representative numbers for air are $M=0.0289$ kg mol^{-1}, $\eta=1.8369\times10^{-5}$ Ns m^{-2}, $\rho=1.2041$ kg m^{-3}. Assuming the chamber to be a 1 mm cube ($V=10^{-9}$ m^3), a 1 sec time constant (i.e., $\tau=1$ sec) can be achieved with a hole of size $r=0.816$ μm. The Knudsen number of the system is 0.04<<1 so the preceding assumption of small Knudsen number is appropriate.

In the preceding analysis, the effects of a finite length to the orifice (so that it acts as a channel) and other parasitic effects such as surface tension are omitted. These effects increase the pneumatic resistance of the pore and enable it to be sized larger for a given time constant τ. It is assumed that one skilled in the art can derive a similar expression or use simulation to account for these effects. The atmospheric permeability of thin polymeric membranes that can also be applied across macro-sized holes in the relatively deep silicon walls of a MEMS produced pressure chamber, or cover arrays of micro-machined surface channels leading to such a chamber can be employed and are well understood. For instance, the O_2 permeability of various common polymers was documented by Robb (1968) to span more than 5 orders of magnitude, making selection of a suitable thickness of gas permeable membrane more a choice of manufacturing convenience then of limited alternative chemistries.

Similarly, gas porous silicon membranes capping a chamber or channels leading to a chamber can be made by MEMS processes with bulk etching & processing techniques to produce predictable gas permeability characteristics. For instance, Galambos, et al. (1999) demonstrated that silicon nitride (Si_3N_4) could itself be etched to produce a gas permeable filter in a micromachined channel. More generally, Wu (2004) described the properties of porous polycystalline membranes etched on Si_3N_4 using MEMS technology to cover cavities. MEMS processing techniques may produce a membrane structure with stochastically predictable micro cracks or pores that facilitate atmospheric gas flow, without the need for precisely machined orifices.

Importantly, the present inventions are neither limited to any single aspect nor embodiment, nor to any combinations and/or permutations of such aspects and/or embodiments. Moreover, each of the aspects of the present inventions, and/or embodiments thereof, may be employed alone or in combination with one or more of the other aspects and/or embodiments thereof. For example, while many of the inventions have been described in connection with a portable monitoring device including one or more altitude sensors (see, for example, FIGS. **1**A-**1**L), many of the inventions may be implemented in connection with a portable monitoring device which does not include one or more an altitude sensors (see, for example, FIGS. **1**M-**1**X). For the sake of brevity, many of those permutations and combinations will not be discussed and/or illustrated separately herein.

Notably, although exemplary embodiments and/or processes have been described above, the inventions described and/or illustrated herein may also be implemented in conjunction with other activity metric determination techniques. As such, the inventions are not limited to processes and/or algorithms implemented in accordance with the flow charts of FIGS. **4**A-**4**R; rather, such flowcharts are merely exemplary.

Further, the portable monitoring device may communicate with external circuitry using the transmitter circuitry (see, for example, FIGS. **1**F, **1**H-**1**L, **1**R and **1**T-**1**X), receiver circuitry (see, for example, FIGS. **1**G, **1**J-**1**L, **1**S, and **1**V-**1**X), removable memory, electrical or optical communication or connector (for example, hardwired communications via USB).

As mentioned above, the portable monitoring device may store and/or transmit the raw data or pseudo-raw (i.e., processed) data from on or more (or all) of the sensor(s). For example, in the context of the motion sensor, the portable monitoring device may store and/or transmit data which is representative of acceleration, angular rate, location and/or compass bearing. In the context of the altitude sensor, in one embodiment, the portable monitoring device may store and/or transmit data which is representative of pressure, altitude, time of flight and/or radar cross section. Further, in the context of the physiological sensor(s) and naturally-derived metrics, the portable monitoring device may store and/or transmit data which is representative of heart waveform (for example, ECG trace), heart rate, blood sugar, blood pressure and/or EEG. In addition, in one embodiment, the portable monitoring device may store and/or transmit data provided by the mode sensor(s) including, for example, bicycling, swimming, skateboard or wheel chair.

Notably, the data which is stored and/or transmitted may be filtered versions of the aforementioned, for example, filtered using passive elements (for example, RC networks) and/or active elements (for example, active electronics), frequency-domain methods (Butterworth filter, etc), statistical methods (Kalman filter, etc), time-series analysis (ARX models, etc) and/or wavelets.

The raw or pseudo-raw (for example, filtered versions) of the aforementioned data may be stored and/or transmitted in time epochs that differ from the original (e.g., 1 Hz instead of 100 Hz) or in summary versions (e.g., mean, variance, integral, power, coefficient of variation, etc.) and may include signal quantities that are derived typically for use in a classification algorithm and other downstream calculations. In addition, the raw or pseudo-raw (for example, filtered versions) of the aforementioned data may be stored and/or transmitted in compressed or uncompressed formats. Such data may also be stored and/or transmitted in a matched to a value format that, for example, captures the approximate or exact value of the data (e.g., look-up table, ranges like "small", "medium" and "large").

The data and parameters derived by the portable monitoring device may be transferred, displayed, and/or modified remotely as in, for example, a computer program or website such as www.fitbit.com. Such content may furthermore be modified by the remote application and transferred back to the device for storage and display. For example, the user may adjust information regarding one or more physiological parameters that effect metabolism, which in turn are used to correct calorie burn estimates on the portable monitoring device. Likewise, the user may adjust information regarding height, step length, the intensity of a workout, the type of activity over a particular time duration (e.g., walking, running, weight lifting, driving or riding in an automobile, etc.) and this information may be used to adjust estimates of calorie burn, distance traveled, speed, avatar state, and other activity-related metrics stored and/or displayed on the portable monitoring device.

Data and derived parameters from one or more of the present inventions and/or one or more other devices may be stored, displayed, and/or modified remotely as in, for example, a computer program or website such as www.fitbit.com. The devices may generate their data independently,

operate dependently upon one another (e.g., as accessories to one another), or both. The remote application may combine the data or generate new data which is then displayed in the remote application and/or other remote applications and/or the portable monitoring device of the present inventions and/or other devices. The remote application may also overlay the data to the user to present a holistic view of the data streams obtained from multiple devices. For example, two devices (called "Device A" and "Device B" for simplicity here which are respectively a pedometer and heart rate monitor) may generate data streams representative of user activity and/or physiological information which is transferred to www.fitbit.com. The user may create a data stream of manually or automatically annotated events on Device B, which are subsequently used by www.fitbit.com to override or modify the data from Device A during the same periods of time as the annotated events. The annotated events may likewise be presented in a manner that attracts user attention preferentially to the data of Device B. Notably, the data that is overridden or modified may be transferred back to Devices A and B for storage and/or display to the user.

In addition, the portable monitoring device may also facilitate social interaction features. In one embodiment, the portable monitoring device may contain user identification "credentials" (for example, stored in memory) that communicate with second or base devices to link a plurality of users (for example, two users) in a social network (for example, via the internet or device-to-device). The second device may or may not be a portable monitoring device according to one or more of the embodiments of the present inventions. As an example, two people may link their devices to become "friends" on www.facebook.com, www.fitbit.com, www.linkedin.com, and/or other social networks. The "friend" status may be may be passed to the internet directly from the device or routed through intermediate devices (e.g., Fitbit Tracker to mobile phone to internet). Linking of devices may be achieved in a variety of well-known ways for pairing two devices. In one embodiment, the two devices may be linked through a bump gesture or physical tapping (e.g., contact) of the two devices that initiates wireless communication between the two. A combination of motion sensing (e.g., accelerometer and/or gyro), and/or magnetic signature sensing, and/or wireless (e.g., NFC, RFID, RF proximity sensing) may be employed.

In other embodiments, the portable monitoring device may provide user contact information such as email addresses, telephone numbers and/or a user name, which may be transmitted when the devices are linked. The device may be configured to transmit only specific pieces of contact information.

In other embodiments, the portable monitoring device may monitor, catalog and/or track the number, duration, frequency, and quality of social interactions between two or more people in a social network. As an example, the portable monitoring device may use wireless proximity detection between portable monitoring devices to determine, monitor, catalog and/or track episodes in which the devices were in the same proximity, for example, to determine, monitor, catalog and/or track the amount of time two users spent time with one another. Summary metrics like the duration of interaction, frequency of meetings, physical distance, etc. are exemplary parameters of interest.

In another embodiment, the portable monitoring device may include one or more audio sensors to monitor, determine and/or track the quality and/or tone of conversation between the user and others (with or without a similarly-equipped device). In yet another embodiment, the same interactions between "friends" in a social network are specifically monitored, cataloged and/or tracked.

In another embodiment, the portable monitoring device may interact with other devices through wireless communication to allow the user to play a game. For example, a pair of devices may be bumped together to initiate a game-like contest between the two users based on their step counts. Other examples may include animated virtual "fight" sequences between avatars placed on both devices. The users' devices may buzz, glow, etc. to notify the users that there is another contestable device nearby. It may do this for "friends" only or for anyone with an appropriate device. The contest may follow deterministic behavior or probabilistic behavior.

Again, in the context of the aforementioned embodiments, the devices may consist of the portable monitoring device according to any of the embodiments described herein and a second device, which may be a second portable monitoring device or may be a different device (for example, a mobile phone or tablet).

Notably, the use of "wireless" also extends to visual and/or magnetic detection and identification of compatible devices. For instance, the invention may have a magnetic field sensor that can recognize the magnetic signature of compatible devices.

As noted above, the portable monitoring device may contain user identification credentials (for example, stored in memory). Here, the portable monitoring device may enable the user to authenticate to certain services or be automatically recognized. For instance, a user attempting to login to "www.fitbit.com" from a computer may be automatically routed to the appropriate, designated, associated and/or correct user account and bypass authentication steps by placing the portable monitoring device into a specific authentication mode, or by virtue of proximity detection of the device by the computer.

Likewise, the user may be automatically identified when approaching other devices that are configured to recognize the invention. For instance, the user may be recognized as she approaches a weight scale that communicates with her device.

In situations where a plurality of portable monitoring devices are "present" in a single location (e.g., a family where each family member owns a device), it may be useful for each portable monitoring device to have a unique identifier so that a user associated with which device may be determined. The indicator may be chosen by the user or it may be preprogrammed onto the device. The indicator may be turned off or disabled by the user. In one embodiment, when the device is placed stationary (e.g., display side up on a table surface) and then subsequently moved or jolted, it displays the indicator. The display may also show other content such as motivational messages, general messages, animations, graphics, etc. In another embodiment, the device may show the same or similar information through an input from the user through the user interface. In yet another embodiment, the device may display the same or similar information when the device is coupled to or removed from a specific fixture (e.g., charger) or put in proximity of fixture (e.g., RF beacon, magnetic source). The unique identifiers comprise a specific color shown on a multicolor LED, color/animation sequence, nickname/keyword, word sequence, vibration sequence, custom avatar, or image.

In one embodiment, the portable monitoring device has a RFID and/or NFC tag embedded in it. The tag may be either read or write. If the tag is read-only, then it stores some static information about the device, for instance, a unique identification number. If the tag is read and write, then either a NFC

writer device can write to it or an onboard MCU is connected to the tag and can write to it. If another device equipped with a NFC reader (e.g., smartphone) is brought in proximity to the device, then an app (e.g., Fitbit mobile app) launches automatically and transfers data with the device (e.g., communication to and from www.fitbit.com). If the application "knows" the portable monitoring device (e.g., it is set up to recognize the device), then it transfers data. If the application sees that the device belongs to someone else, it offers the ability to "friend" that person or establish a similar relationship. It may also show some personal information about the user, who may be a human or nonhuman animal. If the application sees that the device is an unknown device, it offers a setup option. Data transfer functionality may occur directly through the RFID tag itself (e.g., the RFID antenna is connected to an EEPROM that the onboard microprocessor can write to) or the RFID/NFC may act as just an automatic discovery mechanism while data transfer is over another system such as ANT, Bluetooth, Zigbee, Wifi, etc.

In one embodiment, the portable monitoring device is a multi-protocol local area network (LAN) to wide area network (WAN) gateway where local devices may be Bluetooth, ANT, Zigbee, etc. and the gateway communicates to the internet via or over a communication path (for example, a cell phone network, WLAN, etc.). The portable monitoring device may operate as an "open hotspot" so that no user setup is required for subsequent devices. For instance, a user may have elsewhere established a network account (e.g., www.fitbit.com or another website) to the device (e.g., Fitbit Tracker) through its unique device ID, then the device automatically recognizes compatible devices and sends their data to the correct account and location. The data may go directly to the destination or through an intermediary first. Destinations or intermediaries could be other devices or a network service (e.g., www.fitbit.com). The "original" portable monitoring device to account/location link setup could have been done as part of a user initiated setup process or could have been pre-configured as part of the purchasing or acquisition process at the manufacturer or another intermediary. The following is an additional exemplary embodiment:

> A user owns a Garmin ANT device that is set up to sync data to Garmin's website. She then acquires the current invention. Once she connects the invention to the internet, the Garmin device can automatically send its data to Garmin's website through the invention without any further setup. The invention could also send the data to Garmin's website via an intermediary website (e.g., www.fitbit.com).

The user may also turn off and on (disable or enable) the ability for data destinations to receive the data.

The communication circuitry of the portable monitoring device may provide for one-way or two-way communication to, for example, facilitate or provide input of data and/or commands. Indeed, where the device includes two-way communications, the communication circuitry facilitates or provides data or command transmission to and from peripheral devices and/or the Internet. Thus, in certain embodiments, the communication circuitry facilitates or provides external connectivity to, for example, the Internet and/or remote or local external devices and/or appliances.

Where the communication circuitry provides one-way or two-way communication to the Internet and/or (remote or local) external devices and/or appliances, the portable monitoring device may upload data and/or commands to and/or download data and/or commands from, for example, selected websites, health professionals, trainers, weight or health oriented monitoring groups/organizations or specialists, and/or the like (hereinafter collectively "third party" or "third parties"). In this way, the portable monitoring device may manually or automatically provide data to such third parties. The portable monitoring device may also receive data and/or instructions/comments, for example, health or training guidance or feedback via the device. For example, where the portable monitoring device provides data (for example, activity levels, steps and/or sleep quality) to one or more third party devices or websites, such third parties (for example, health professionals or trainers) may monitor and/or provide feedback based on such data. In this way, such third party or parties may provide periodic, continuous and/or intermittent monitoring and/or feedback, notwithstanding the user/patient is substantially remote or distant from such third parties, or where significant monitoring of the user/patient is inconvenient or not feasible (for example, due to costs or locations).

The communication circuitry may also facilitate programming of the portable monitoring device, for example, programming the device to acquire selected data (via enabling and/or disabling selected sensors) and/or calculate, monitor and/or determine selected physiological parameters (via enabling or disabling the processing circuitry accordingly). The programming of the portable monitoring device may be via the user or third party. In this way, for example, a third party may customize or tailor the acquisition of physiological data based on the user, the situation (for example, physical condition of the user), and the acquisition of desired information.

In certain embodiments, the portable monitoring device may also operate, program and/or control local external devices and/or appliances. For example, the communication circuitry of the device may also function as a relay or hub to provide or facilitate communication for external devices to each other or to the Internet. For example, the device may connect to the Internet via WLAN but also be equipped with an ANT radio. An ANT device may communicate with the device to transmit its data to the Internet through the WLAN of the device (and vice versa). Moreover, where the communication circuitry is equipped with Bluetooth, other Bluetooth-enabled devices (for example, mobile or smart telephones) that come within suitable or effective reach or range, the device may transmit data to or receive data from such Bluetooth-enable device and/or the Internet through the network of the mobile or smart telephones. Indeed, data from another device may also be transmitted to the device and stored (and vice versa) or subsequently transmitted at a later time.

In another preferred embodiment, the portable monitoring device is a single protocol or multi-protocol wireless bridge that may relay, store, and/or display data from compatible wireless devices. Compatible devices need not be activity monitors. For example, a weight scale may transmit data of the user's weight to the device and it may display an historical graph of the user's weight. Data transfer may be bidirectional. Data may be stored and later transferred through the device's wireless communication circuitry to other services such as the Internet.

In a preferred embodiment, when the portable monitoring device is placed stationary (e.g., display side up or display side down on a table surface), it attempts wireless communication with nearby compatible wireless devices. Indeed, in several embodiments a wireless communication attempt is initiated by the portable monitoring device through one or more gestures detected by the motion sensor. For instance, the device may be placed display side up on a surface for a fixed time interval then subsequently flipped to the display side down position.

As mentioned above, the portable monitoring device may include a user interface having a display. In one embodiment, the display is customizable in that the information and content of the display may be customized by the user. The user may configure the types of information "screens" as they show up on the device and in which order. This may be achieved through configuration on the device or an external application (e.g., a settings manager on www.fitbit.com). As indicated above, the portable monitoring device, in addition to monitoring, calculating and/or determining of one or more activity and physiological parameters (based on or using data from resident sensors), may receive web content for display on the user interface of the portable monitoring device. The following are examples of the types and/or content of information that may be provided to the user.

- Historical and current graphs and/or data of user activity and/or foods consumed and/or sleep data that are measured by the device and/or stored remotely (e.g., fitbit.com);
- Historical graphs and data of user weight and/or body fat data measured by a weight scale and transferred to the device (either over the Internet or by the scale itself);
- Historical graphs and data of other user-tracked data measured by the device or stored remotely. Examples include heart rate, blood pressure, arterial stiffness, blood glucose levels, cholesterol, duration of TV watching, duration of video game play, mood, etc.;
- Physiological data corresponding to average or norms, for example, for comparison purposes wherein, in one embodiment, the user's physiological data is compared to or contrasted with average physiological data (for example, on an age, gender or condition basis (for example, a pregnant women's physiological data is compared with typical physiological data based on stage, size and age));
- "Mash-up" data pertaining to user's physiologic data and user's water intake—for example, correlations of (i) hydration levels to manually logged water consumption and (ii) hydration levels to automatically measured water consumption via a "smart" water bottle (e.g., Camelbak flow meter hydration gauge system);
- "Mash-up" data pertaining to user's physiologic data and user's sleep—for example, correlations of (i) heart rate to blood pressure and (ii) body weight and/or fat to sleep time, patterns and/or quality;
- "Mash-up" data pertaining to user's physiologic data and user's activity—for example, correlations of (i) hydration to activity levels and (ii) heart rate and/or variability to activity levels and/or patterns;
- "Mash-up" data pertaining to physiologic data and potentially related external events such as correlations of (i) user's body weight and/or fat to ambient environment for example, geography, temperature and/or weather, (ii) user's heart rate and/or blood pressure to financial markets (for example, S&P 500, NASDAQ or Dow Jones); here the data analysis of the user's biometric or physiologic data is correlated to web content and/or external devices that are in communication with the biometric monitoring device;
- Coaching and/or dieting data based on one or more of the user's current weight, weight goals, food intake, activity, sleep, and other data;
- User progress toward weight, activity, sleep, and/or other goals;
- Summary statistics, graphics, badges, and/or metrics (e.g., "grades") to describe the aforementioned data;
- The aforementioned data displayed for the user and his/her "friends" with similar devices and/or tracking methods;
- Social content such as Twitter feeds, instant messaging, and/or Facebook updates;
- Other online content such as newspaper articles, horoscopes, stock, sports or weather reports, RSS feeds, comics, crossword puzzles, classified advertisements, and websites; and
- Motivational messages, system messages (e.g., battery status, "sync data" notifier), device communications that may be similar to social content (e.g., the device may communicate greetings to the user like "Hello", "Good Morning"), and/or other messages similar in content to a fortune cookie; and
- Email messages and calendar schedules; and
- Clock and/or stop watch.

For the avoidance of doubt, it should be understood that these examples are provided for illustration and are not intended to limit the inventions, including the scope of data that may be transmitted, received, or displayed by the device, nor any intermediate processing that may employed during such transfer and display.

Notably, selected content may be delivered according to different contexts. For example, in the morning, motivational messaging may be displayed along with the user's sleep data from the previous night. In the evening, a daily summary of the day's activities may be displayed. Notably, sleep and activity may be monitored and derived from other devices, manual log entries on a website, etc.—not the present invention. Such information, however, may be communicated to, for example, the user and/or the Internet via the device.

Furthermore, in several embodiments the device has a motivational avatar whose state is dependent on user activity. Nominally, the avatar may be a "flower" or plant that grows and shrinks as a function of the duration and intensity of a user's physical activity over a period of several hours. In a preferred embodiment, the device may be programmed with a customizable avatar and the behavior of the avatar may change over time as the user interacts with the device. The device may also be programmed with optional games and interventions to help the user meet goals.

Programming or customizing may be implemented via the user interface, an external device via the communication circuitry (for example, via wired or wireless connection to a computer or personal computing device) and/or through a web interface (e.g., www.fitbit.com) on the user interface of the device. Similarly, the firmware loaded on the device may be updated and configured by the user through the communication circuitry (for example, via wireless connection). Indeed, functions and features of the device (for example, certain sensors or data processing) as described here may also be modified, enabled and/or disabled (for example, on an individual basis or global basis).

In a preferred embodiment, the portable monitoring device may be mounted to different parts of the user and/or exercise equipment to perform functions that are specific or adapted to its location. For example, when mounted on the torso, the portable monitoring device may monitor the user's steps, distance, pace, calorie burn, activity intensity, altitude gain/loss, stair steps, etc. based on data from the motion sensor and altitude sensor using one set of algorithms. When the portable monitoring device is mounted to the user's foot, the device may monitor the same or similar parameters using possibly a different sensor configuration and another set of algorithms. Additionally, it the portable monitoring device may monitor the impact accelerations present on the foot to determine 1) if the user is running with soft or hard footfalls or 2) if the user

is running on a soft or hard surface (e.g., the amount of time spent running on concrete vs. grass). When the portable monitoring device is mounted to the wrist, arm, hand, it may perform sleep tracking functionality, swimming functionality, ambulatory activity functionality, or stress biofeedback functionality using, in part or wholly, a heart rate and/or respiratory rate sensor and/or galvanic skin response (GSR) sensor—the determination of which mode of operation may be determined automatically through mode or motion sensor data, or the user may place the device into the appropriate mode manually.

Note that in the case of the hand, the portable monitoring device may be held rather than mounted. In a preferred embodiment, a gesture of the device mostly contained in the orthogonal plane to the gravitational vector may be used as a user interface mechanism (e.g., to navigate a menu system). Because the gesture is mostly orthogonal to gravity, it may be reliably distinguished between other motions that produce signals that are mostly parallel to gravity (e.g., walking, running, and jumping). In a preferred embodiment, the gesture is similar to the flick of the wrist (as typically produced when dealing cards or throwing a flying disc) and/or the reverse motion toward the body. Due to the fast motion of this gesture, it may be readily distinguished from other motions that are orthogonal to gravity (e.g., hip rotations). In lieu of or in combination with the preceding gesture, the device may incorporate another gesture wherein the direction of gravity relative to one or more axes of an accelerometer begins in a first orientation, then is moved to a second orientation that is roughly 90° degrees different, then returned to the first orientation. For example, in the case of a device with a 3D accelerometer, a 1 g acceleration may be sensed on one accelerometer axis in the first orientation (and close to 0 g on both other axes), then go to near 0 g in the second orientation (and close to 1 g on one of the other axes), then return to 1 g when the device is returned to the first orientation. Because such rotations do not occur often in natural use of an activity monitoring device, it may be readily used as a gesture for user interactions. Notably, these gestures may be recognized with a variety of sensors other than or in combination with an accelerometer such as a magnetic compass, gyroscope, mechanical switch, etc.

In regards to swim tracking, the use of inertial and/or magnetic sensors (e.g., compasses) may be used to determine the lap count of the user. Speed and distance may subsequently be calculated based on a configured lap length. When the device is placed on a bicycle hub or wheel, it may perform bicycle activity tracking (e.g., cadence, calorie burn).

As mentioned before, the portable monitoring device may also transmit its data to a secondary display device so that the user may see its output in real-time. In another embodiment, the device may communicate with another activity monitoring device (e.g., ANT-enabled heart rate monitor) either directly or indirectly through a wireless bridge (e.g., a smart phone that routes data from one device to another, or between both). When the portable monitoring device is placed on a free weight or weight training apparatus, it may perform functions related to weight training (e.g., tracking repetitions, sets, time between repetitions/sets, type of exercise, form.).

In another aspect of the present inventions, the portable monitoring device may select which sensors and algorithms to use based on its mounting condition. For instance, if the device is mounted to the arm, it uses an optical heart rate monitor to calculate calorie burn. If the portable monitoring device is mounted to the torso, it uses an accelerometer to calculate calorie burn. In this example, the device may determine its location partially or wholly from the quality of the heart rate signal: if no signal is present, the device is not mounted to the arm. In this example, mounting conditions may furthermore be determined through the design of the mounting fixtures. For example, the fixtures may have reflective and anti-reflective materials which enable the device to optically distinguish between a mounting to the torso and/or to the foot. Notably, the optical module in the portable monitoring device may incorporate an array of emitters (e.g., LEDs) and/or an array of detectors (e.g., photodiodes, photodetectors, photoresistors) wherein the emitters/detectors have different locations relative to the body and may be used to find the best signal locations while reducing power consumption (by, for instance, dimming or turning off some emitters/detectors).

Other embodiments may employ fixtures and devices which have magnets and/or magnetic sensors (e.g., Hall effect sensors), RF beacons and transmitters, buttons, electrical contacts, proximity sensors, etc. The portable monitoring device may also be equipped with a magnetic field sensor which is used to recognize the magnetic signature of fixtures and other devices.

Note that an optical system for heart rate sensing may also be used to sense respiratory rate. The two signals are modulated into a single photoplethysmography (PPG) signal. When applied to stress biofeedback, the PPG sensor may provide information on heart rate, heart rate variability, and respiratory rate. This may be supplemented or supplanted with information from a GSR sensor in the device. The same information may be used with or without the motion sensor to assist in sleep tracking, specifically as they relate to sleep onset and sleep stages. In other embodiments of the invention, the device may also include ambient light sensing, noise sensing, as well as all possible combinations of the previously mentioned sensors. When mounted to the arm and used in ambulatory activity monitoring, the PPG-derived information may be displayed to the user on a secondary device such as a wrist-mounted watch.

Notably, when the portable monitoring device is mounted to the torso, a combination of motion sensing and altitude sensing may be used to detect periods in which the user is sitting, standing, and lying down.

The portable monitoring device may also include one or more environmental sensors to detect, measure and/or sense ambient environmental conditions. For example, the one or more environmental sensors may detect, measure and/or sense ambient pressure, temperature, sound, light, humidity, location and/or atmosphere. In this manner, the portable monitoring device may monitor, in addition to user activity, other metrics related to noise pollution/levels, weather, UV exposure, lighting conditions, and/or air quality.

In another embodiment, the portable monitoring device may monitor the RF signature of nearby devices in order to determine its location. For instance, a home may have a set of Bluetooth or ANT devices that are beaconing to form a signature for the home. Indeed, the portable monitoring device may monitor the signature in order to determine its location in the home. The portable monitoring device may also determine its location directly from a GPS-enabled device that has a compatible communication protocol with the invention (e.g., a Bluetooth enabled smart phone). The portable monitoring device may also use a barometric pressure sensor to determine the user's altitude. (Obviously, other communication protocols can be used too, like RFID, WiFi, NFC, etc).

The portable monitoring device may include a rechargeable battery or ultracapacitor to provide electrical power to the circuitry and other elements of the portable monitoring

device. In one embodiment, the energy storage element (for example, battery or ultracapacitor) may obtain energy from, for example, a charger.

In one embodiment, the portable monitoring device includes an active or passive energy harvesting circuitry wherein the energy acquired, obtained and/or generated by the circuitry is employed to immediately power the device or stored in, for example a rechargeable battery or ultracapacitor for later use by the a rechargeable battery or ultracapacitor.

With references to FIGS. **15**A-**15**C, the energy harvesting circuitry portable monitoring device may convert the movement of the user to energy, using, for example, elements, circuitry and/or techniques which generate energy in response to the movement of the user (for example, moving magnets and/or piezoelectric elements). In this regard, the portable monitoring device passively "harvests" or converts the kinetic energy supplied by the user (for example, via movement) to charge the battery or ultracapacitor, supplement such charge, and/or immediately power the device. For example, the device may incorporate piezoelectric elements that generate current in response to user motion and associated circuitry to rectify and store said current. In lieu of or in combination, the device may incorporate a magnet that may move within an inductive coil such that motion of the device induces a current through the coil. The coil may be shaped as a cylinder, for example, to capture the motion shocks during user movement or ambulation, or it may be shaped as a toroid so that the magnet may move easily under other conditions.

In another embodiment, the portable monitoring device includes circuitry to "harvest" or acquire the energy from signals in the surrounding atmosphere. In this embodiment, the energy harvesting circuitry converts the energy of or in those signals to charge the battery or ultracapacitor, supplement such charge, and/or immediately power the device.

As mentioned above, at least a portion of the portable monitoring device (including the one or more altitude sensors and/or motion sensors) may be affixed to the user during operation wherein the portable monitoring device includes a physical size and/or shape that facilitates coupling to the user, for example, the body of the user (such as, for example, arm, wrist, angle, waist and/or foot) and allows the user to perform normal or typical user activities (including, for example, exercise of all kinds and type) without hindering the user from performing such activities. (See, for example, FIGS. **16**A-**16**D and **17**). The portable monitoring device may include a mechanism (for example, a clip, strap and/or tie) that facilitates coupling or affixing the device to the user during such normal or typical user activities. A base station may facilitate interface to a second device (for example, computer) and/or recharging of the battery. (See, for example, FIG. **16**D).

It should be noted that the term "circuit" may mean, among other things, a single component or a multiplicity of components (whether in integrated circuit form or otherwise), which are active and/or passive, and which are coupled together to provide or perform a desired function. The term "circuitry" may mean, among other things, a circuit (whether integrated or otherwise), a group of such circuits, one or more processors, one or more state machines, one or more processors implementing software, one or more gate arrays, programmable gate arrays and/or field programmable gate arrays, or a combination of one or more circuits (whether integrated or otherwise), one or more state machines, one or more processors, one or more processors implementing software, one or more gate arrays, programmable gate arrays and/or field programmable gate arrays. The term "data" may mean, among other things, a current or voltage signal(s) whether in an analog or a digital form, which may be a single bit (or the like) or multiple bits (or the like).

It should be further noted that the various circuits and circuitry disclosed herein may be described using computer aided design tools and expressed (or represented), as data and/or instructions embodied in various computer-readable media, for example, in terms of their behavioral, register transfer, logic component, transistor, layout geometries, and/or other characteristics. Formats of files and other objects in which such circuit expressions may be implemented include, but are not limited to, formats supporting behavioral languages such as C, Verilog, and HLDL, formats supporting register level description languages like RTL, and formats supporting geometry description languages such as GDSII, GDSIII, GDSIV, CIF, MEBES and any other suitable formats and languages. Computer-readable media in which such formatted data and/or instructions may be embodied include, but are not limited to, non-volatile storage media in various forms (e.g., optical, magnetic or semiconductor storage media) and carrier waves that may be used to transfer such formatted data and/or instructions through wireless, optical, or wired signaling media or any combination thereof. Examples of transfers of such formatted data and/or instructions by carrier waves include, but are not limited to, transfers (uploads, downloads, e-mail, etc.) over the Internet and/or other computer networks via one or more data transfer protocols (e.g., HTTP, FTP, SMTP, etc.). The present inventions are also directed to such representation of the circuitry described herein, and/or techniques implemented thereby, and, as such, are intended to fall within the scope of the present inventions.

Indeed, when received within a computer system via one or more computer-readable media, such data and/or instruction-based expressions of the above described circuits may be processed by a processing entity (e.g., one or more processors) within the computer system in conjunction with execution of one or more other computer programs including, without limitation, net-list generation programs, place and route programs and the like, to generate a representation or image of a physical manifestation of such circuits. Such representation or image may thereafter be used in device fabrication, for example, by enabling generation of one or more masks that are used to form various components of the circuits in a device fabrication process.

Moreover, the various circuits and circuitry, as well as techniques, disclosed herein may be represented via simulations and simulation instruction-based expressions using computer aided design, simulation and/or testing tools. The simulation of the various sensors, processing circuitry, user interface, transmitter circuitry and/or receiver circuitry of the present inventions (regardless of combination or permutation of sensors, processing circuitry, transmitter circuitry and/or receiver circuitry), including the processes or techniques implemented thereby, may be implemented by a computer system wherein characteristics and operations of such circuitry, and techniques implemented thereby, are simulated, imitated, replicated, analyzed and/or predicted via a computer system. The present inventions are also directed to such simulations and testing of the inventive portable monitoring device (or portions thereof including, for example, the various sensors, processing circuitry, user interface, input/output circuitry (although not illustrated—the input/output circuitry may be discrete circuitry or circuitry which is integrated into the processing circuitry), transmitter circuitry and/or receiver circuitry), and/or techniques implemented thereby, and, as such, are intended to fall within the scope of the present inventions. The computer-readable media and data corre-

sponding to such simulations and/or testing tools are also intended to fall within the scope of the present inventions.

The term "calculate" and other forms (i.e., calculating, calculated and calculation) in the claims means, among other things, calculate, assesses, determine and/or estimate and other forms thereof. In addition, the term "calorie burn" in the claims means, among other things, calorie burn or calorie expenditure and/or energy burn or energy expenditure—or the like.

Further, in the claims, the phrase "data which is representative of a change in altitude" means data which is representative of an altitude of the user (absolute altitude) and data which is representative of a change in altitude (relative altitude). Further, in the claims, the phrase "a change in altitude" means a change in altitude or height. Moreover, for the avoidance of doubt, in the claims, the term "flights of stairs" means "flights of stairs", "floors" and the like.

Notably, the terms "first," "second," and the like, herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. Moreover, in the claims, the terms "a" and "an" herein do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

What is claimed is:

1. A portable activity monitoring device to calculate activity points corresponding to physical activities of a user, the portable activity monitoring device comprising:

a housing having a physical size and shape that is adapted to couple to the body of the user;

a plurality of sensors, disposed in the housing, to generate sensor data which is representative of activity of the user, wherein the plurality of sensors includes at least three accelerometers;

processing circuitry, disposed in the housing and electrically coupled to the plurality of sensors, to:

calculate the activity points of the user using the sensor data, wherein the activity points correlate to an amount of one or more physical activities of the user; and

a display, coupled to the processing circuitry, to output the data which is representative of the activity points to the user.

2. The portable activity monitoring device of claim **1** wherein the processing circuitry further calculates, based on or using the activity points, a state of an avatar, a badge and/or an activity grade.

3. The portable activity monitoring device of claim **1** wherein the plurality of sensors includes two or more of a motion sensor, an altitude sensor and a physiological sensor.

4. The portable activity monitoring device of claim **1** wherein the plurality of sensors includes a motion sensor and a physiological sensor.

5. The portable activity monitoring device of claim **1** wherein the plurality of sensors includes an altitude sensor and a physiological sensor.

6. The portable activity monitoring device of claim **1** wherein the plurality of sensors includes an altitude sensor.

7. The portable activity monitoring device of claim **1** wherein the plurality of sensors includes a motion sensor and a physiological sensor.

8. The portable activity monitoring device of claim **1** wherein the sensor data includes data which is representative of a change in elevation, user speed, step frequency, stair steps and/or heart rate.

9. The portable activity monitoring device of claim **1** wherein the activity points correspond to one or more of a biking, location, walking/running activity, swimming, distance and motion activity.

10. A portable activity monitoring device to calculate activity points corresponding to a physical activity of a user, the portable activity monitoring device comprising:

a housing having a physical size and shape that is adapted to couple to the body of the user;

at least one sensor, disposed in the housing, to generate sensor data which is representative of ambulatory activity of the user, wherein the at least one sensor includes a tri-axial accelerometer;

processing circuitry, disposed in the housing and electrically coupled to the at least one sensor, to:

calculate the activity points corresponding to the physical activity of the user using the sensor data, wherein the activity points correlate to an amount and intensity of the physical activity of the user; and

a display, coupled to the processing circuitry, to output the data which is representative of the activity points to the user.

11. The portable activity monitoring device of claim **10** wherein the processing circuitry further calculates, based on or using the activity points corresponding to the physical activity of the user, a state of an avatar, a badge and/or an activity grade.

12. The portable activity monitoring device of claim **10** wherein sensor data is data is representative of a change in elevation of the user.

13. The portable activity monitoring device of claim **10** wherein the at least one sensor is an altitude sensor.

14. The portable activity monitoring device of claim **10** wherein activity points correlate to changes in altitude of the user.

15. The portable activity monitoring device of claim **10** wherein activity points correlate to (i) changes in altitude of the user and (ii) user speed, step frequency, energy expenditure and/or heart rate.

16. The portable activity monitoring device of claim **10** wherein activity points correlate to (i) changes in altitude of the user or (ii) user speed, step frequency, and/or calorie burn.

17. A portable activity monitoring device to calculate activity points corresponding to a physical activity of a user, the portable activity monitoring device comprising:

a housing having a physical size and shape that is adapted to couple to the body of the user;

a motion sensor, disposed in the housing, to generate data which is representative of motion of the user;

an altitude sensor, disposed in the housing, to generate data which is representative of changes in altitude of the user;

processing circuitry, disposed in the housing and electrically coupled to the motion sensor and altitude sensor, to:

calculate the activity points corresponding to the physical activity of the user using the sensor data, wherein the activity points correlate to the physical activity of the user; and

a display, coupled to the processing circuitry, to output the data which is representative of the activity points to the user.

18. The portable activity monitoring device of claim **17** further including a physiological sensor, disposed in the housing and electrically coupled to the processing circuitry, to generate data which is representative of physiological information of the user.

19. The portable activity monitoring device of claim **18** wherein the processing circuitry further calculates blood pressure, heart rate, respiration rate, skin conduction, blood glucose, blood oxygenation, skin temperature, body temperature, electromyography and/or electroencephalography of the user using the data which is representative of physiological information of the user.

20. The portable activity monitoring device of claim **17** wherein the processing circuitry calculates the activity points based on (i) changes in altitude of the user and (ii) user speed, step frequency, calorie burn, energy expenditure and/or heart rate of the user.

21. The portable activity monitoring device of claim **17** wherein the processing circuitry calculates the activity points based on (i) changes in altitude of the user and (ii) user speed, step frequency, and/or calorie burn of the user.

22. The portable activity monitoring device of claim **17** wherein activity points correlate to (i) changes in altitude of the user and (ii) user speed, step frequency, surface grade, stair steps, calorie burn, energy expenditure and/or heart rate.

23. The portable activity monitoring device of claim **17** wherein the processing circuitry further calculates, based on or using the activity points corresponding to the physical activity of the user, a state of an avatar, a badge and/or an activity grade.

24. The portable activity monitoring device of claim **17** wherein the portable activity monitoring device further includes:

a user interface, and

wherein the processing circuitry (i) detects one or more user inputs to the user interface using data generated by the motion sensor, and (ii) outputs the data which is representative of the activity points in response to detecting the one or more user inputs to the user interface.

25. A portable activity monitoring device to calculate activity points corresponding to a physical activity of a user, the portable activity monitoring device comprising:

a housing having a physical size and shape that is adapted to couple to the body of the user;

a plurality of sensors, disposed in the housing, to generate sensor data which is representative of activity of the user, wherein the plurality of sensors includes at least three accelerometers;

processing circuitry, disposed in the housing and electrically coupled to the plurality of sensor, to

calculate the activity points corresponding to the physical activity of the user using the sensor data, wherein the activity points correlate to an amount and intensity of the physical activity of the user; and

a display, coupled to the processing circuitry, to output the data which is representative of the activity points to the user.

26. The portable activity monitoring device of claim **25** wherein the plurality of sensors includes a motion sensor and an altitude sensor.

27. The portable activity monitoring device of claim **25** wherein the portable activity monitoring device further includes:

a user interface, and

wherein the processing circuitry (i) detects one or more user inputs to the user interface using data generated by the motion sensor, and (ii) outputs the data which is representative of the activity points in response to detecting the one or more user inputs to the user interface.

28. The portable activity monitoring device of claim **25** wherein the processing circuitry further calculates, based on or using the activity points corresponding to the physical activity of the user, a state of an avatar, a badge and/or an activity grade.

29. The portable activity monitoring device of claim **25** wherein the processing circuitry calculates the activity points based on (i) changes in altitude of the user and (ii) user speed, step frequency, and/or calorie burn of the user.

* * * * *

EXHIBIT C

US009089760B2

(12) **United States Patent**
Tropper et al.

(10) **Patent No.: US 9,089,760 B2**
(45) **Date of Patent: *Jul. 28, 2015**

(54) **SYSTEM AND METHOD FOR ACTIVATING A DEVICE BASED ON A RECORD OF PHYSICAL ACTIVITY**

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(58) **Field of Classification Search**

None

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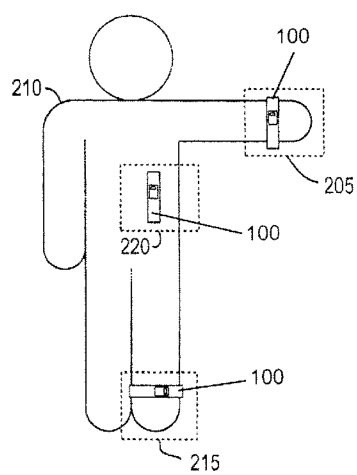
(57) **ABSTRACT**

In a redeemable coupon there is a housing, a motion detector coupled to the housing, wherein the motion detector detects an amount of motion of the coupon, and an indicator coupled to the motion detector, wherein the indicator is activated by the motion detector upon detecting the amount of motion. Additionally, in a method of providing an incentive for a user to exercise, providing the user with a coupon to be coupled to the user, monitoring the motion of the user with a motion sensor included in the coupon, and activating the coupon when the motion sensor has detected a predetermined amount of motion such that the coupon becomes redeemable by the user.

22 Claims, 18 Drawing Sheets



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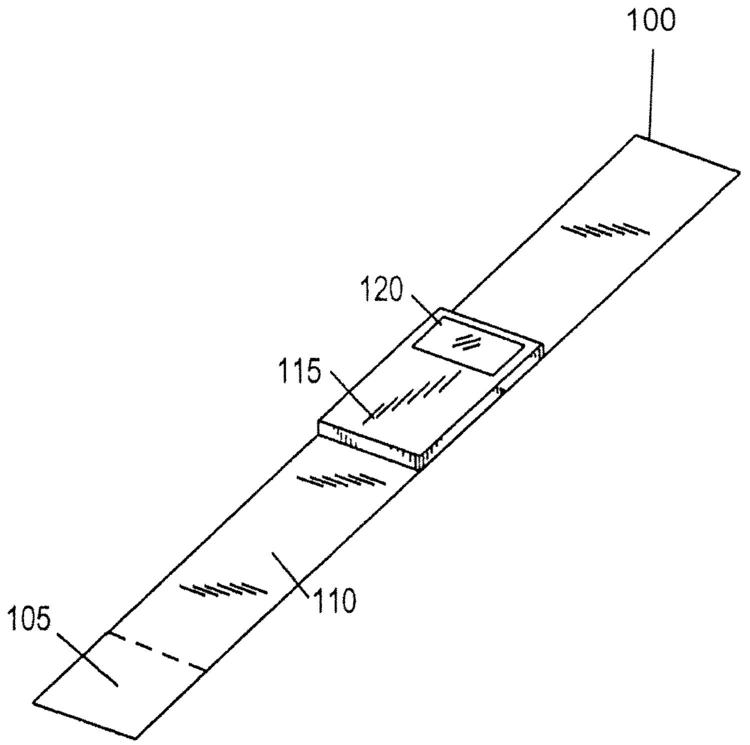


FIG. 1

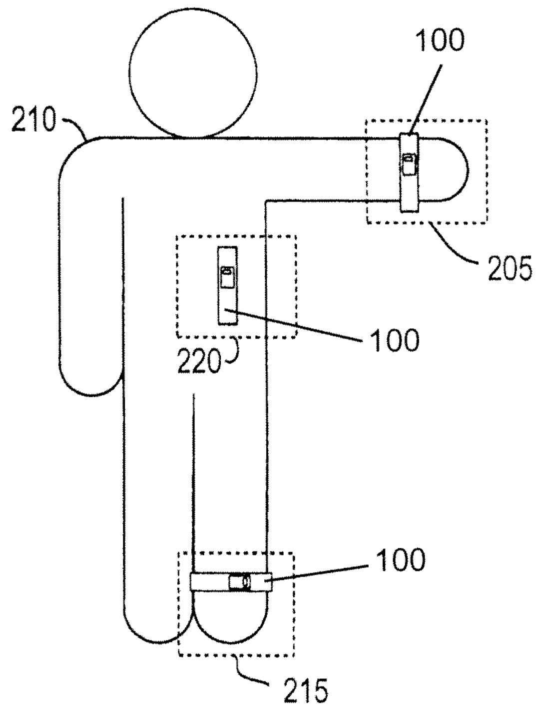


FIG. 2

FIG. 3A

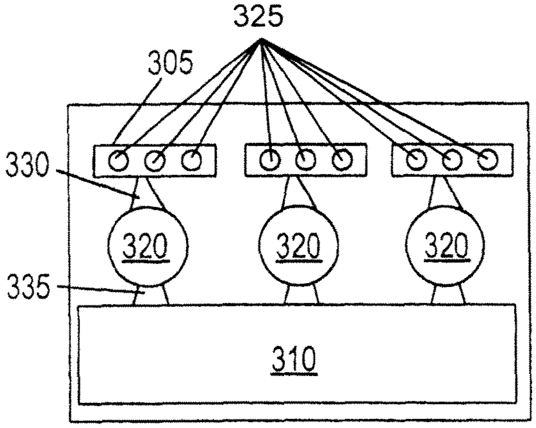


FIG. 3B

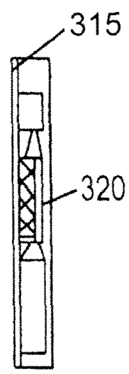
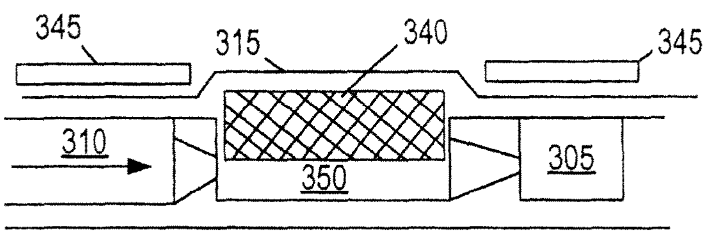


FIG. 3C



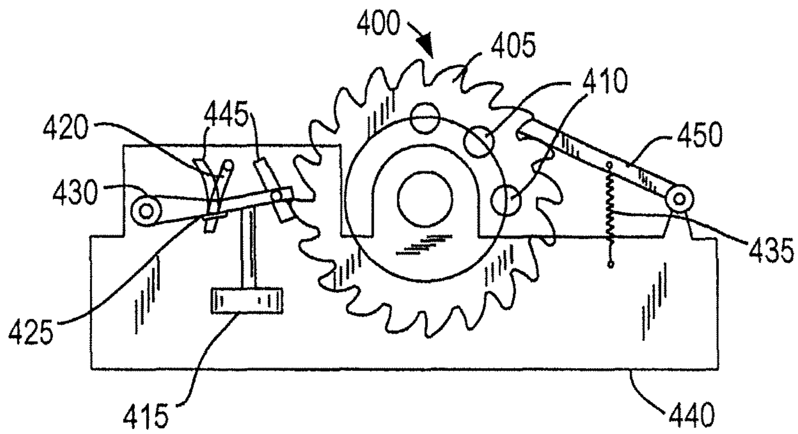

400
405
410
420
445
450
430
435
425
415
440

FIG. 4

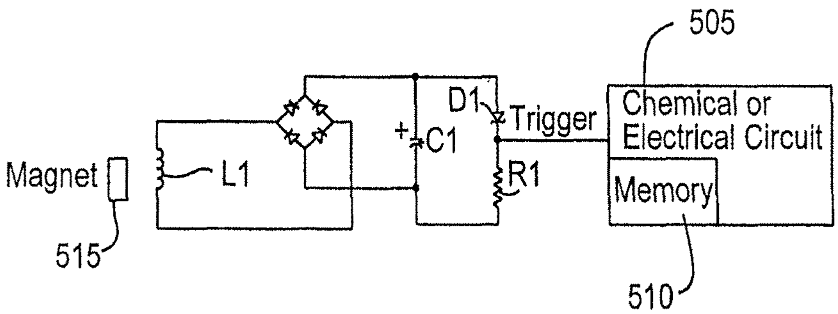

505
D1
Trigger
Chemical or
Electrical Circuit
+
C1
Magnet
L1
R1
Memory
515
510

FIG.5

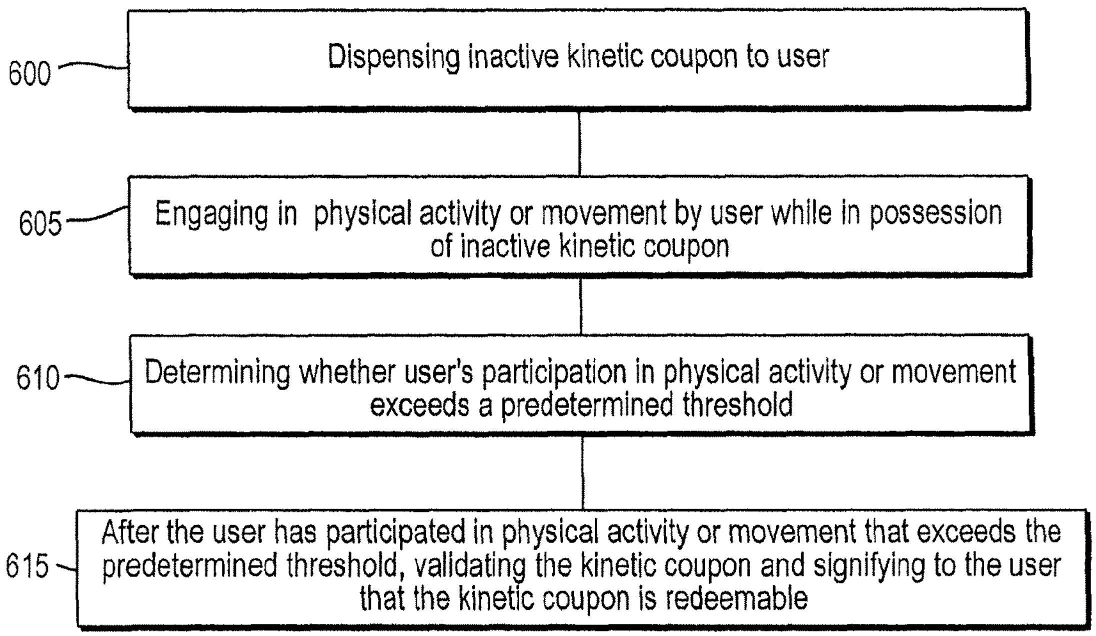

600
Dispensing inactive kinetic coupon to user
605
Engaging in physical activity or movement by user while in possession of inactive kinetic coupon
610
Determining whether user's participation in physical activity or movement exceeds a predetermined threshold
615
After the user has participated in physical activity or movement that exceeds the predetermined threshold, validating the kinetic coupon and signifying to the user that the kinetic coupon is redeemable

FIG.6

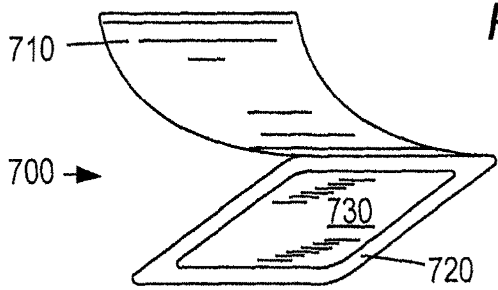


FIG. 7A

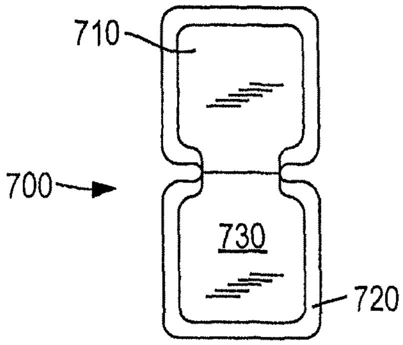


FIG. 7B

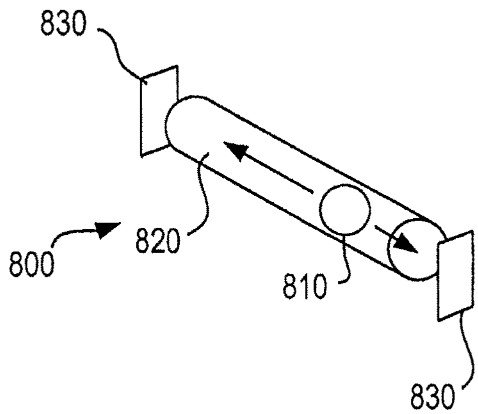


FIG. 8A

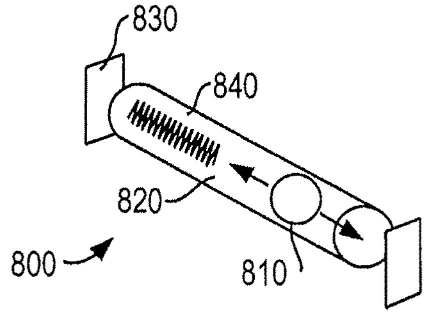
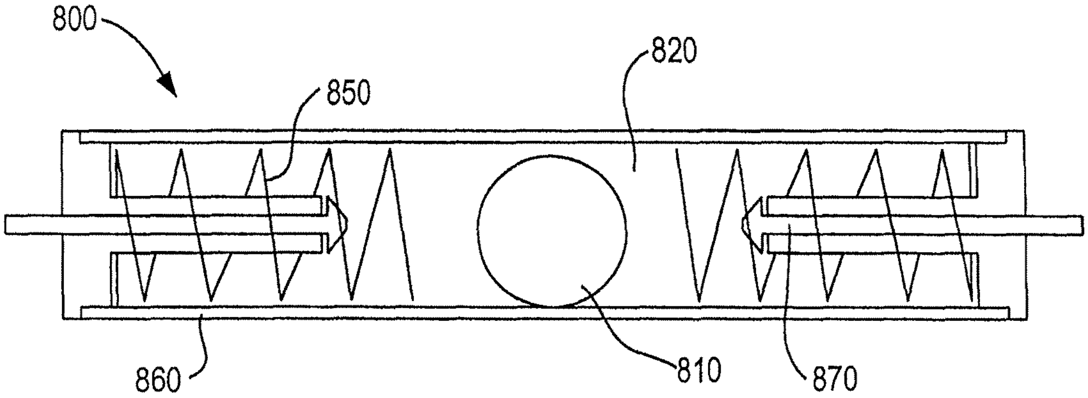


FIG. 8B

FIG. 8C



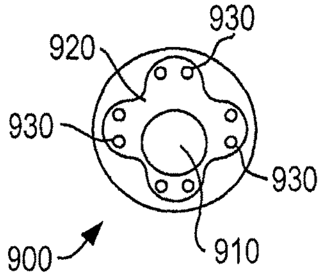


FIG. 9

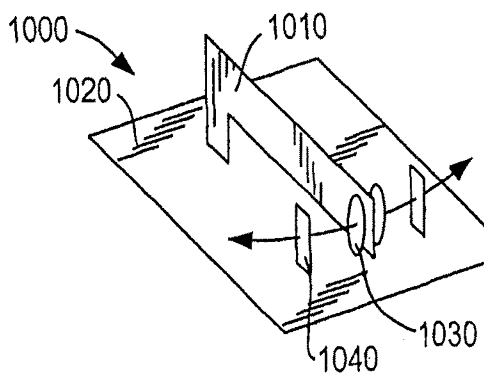

1000
1010
1020
1030
1040

FIG. 10

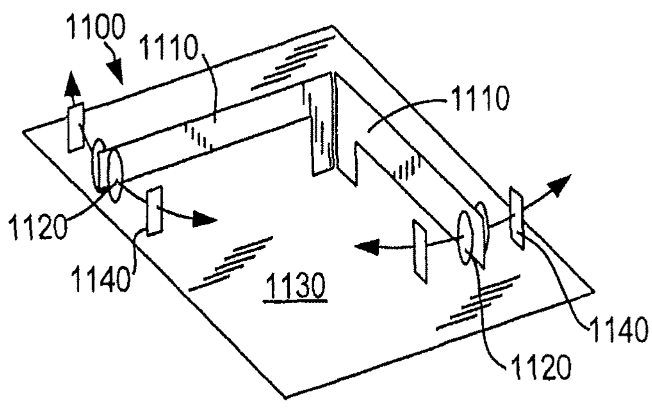

1100
1110
1110
1120
1140
1130
1140
1120

FIG. 11

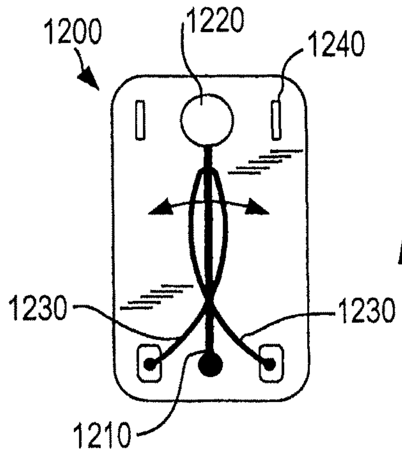


FIG. 12

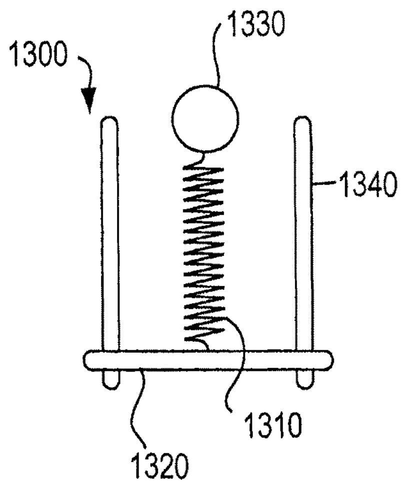


FIG. 13

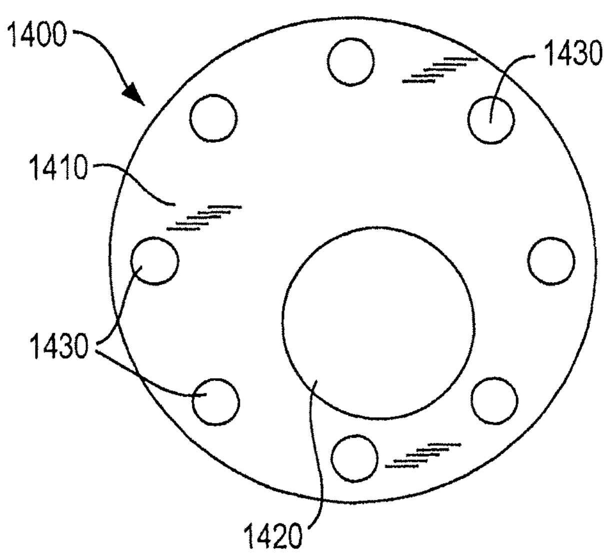


FIG. 14

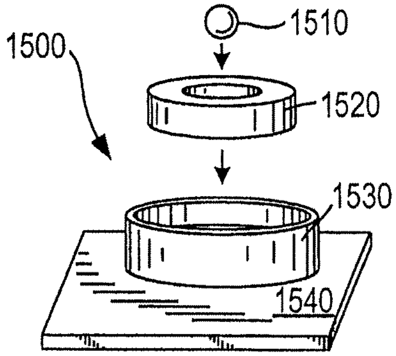


FIG. 15A

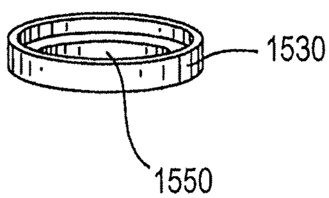


FIG. 15B

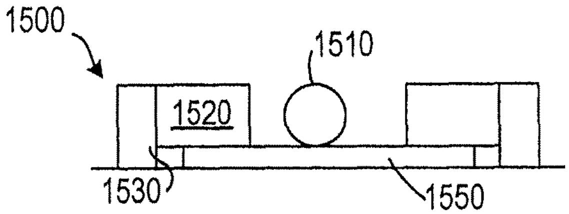


FIG. 15C

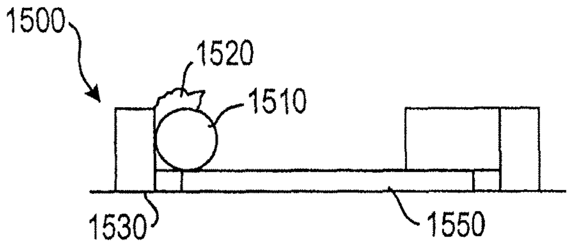


FIG. 15D

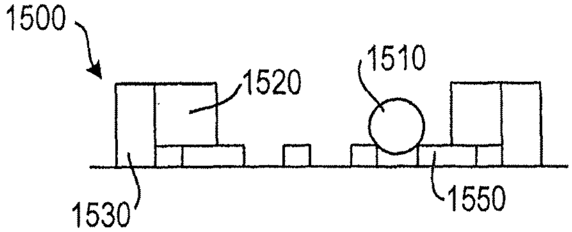


FIG. 15E

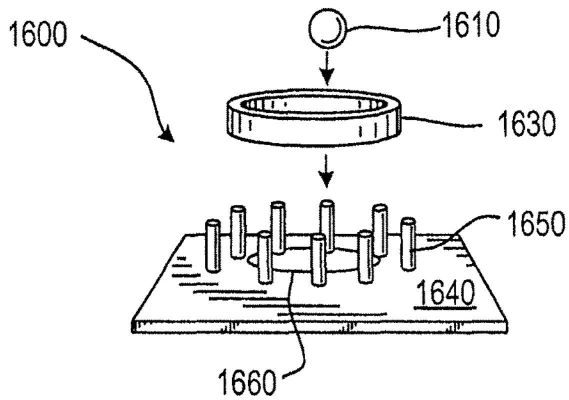

1600
1610
1630
1650
1640
1660

FIG. 16

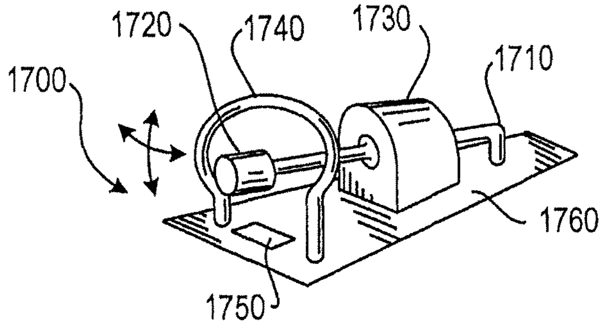

1720
1740
1730
1710
1700
1760
1750

FIG. 17

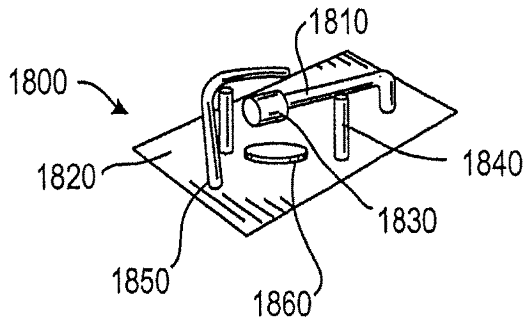


FIG. 18A

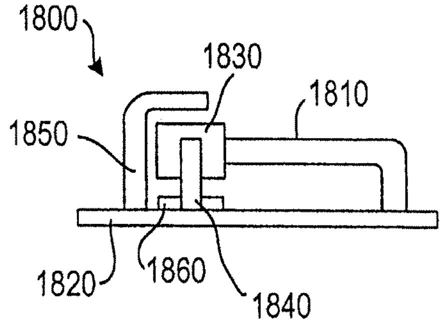


FIG. 18B

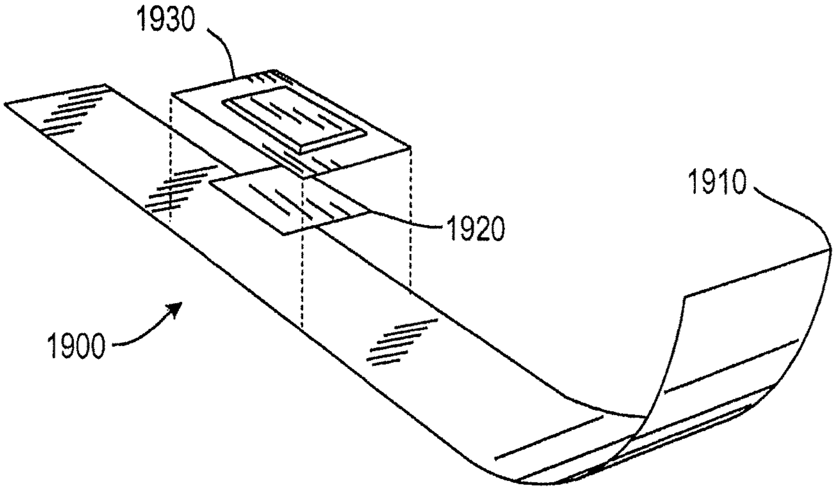


FIG. 19

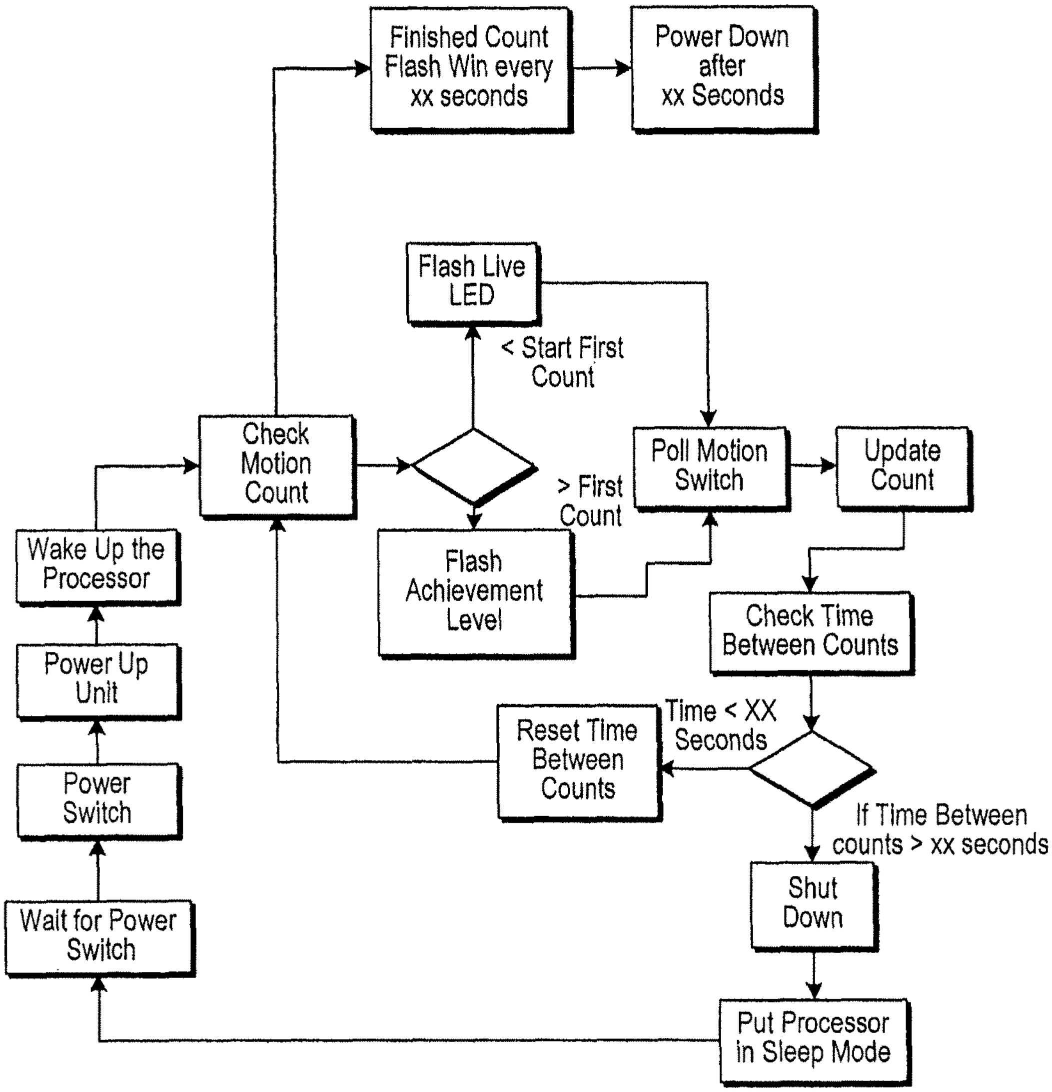
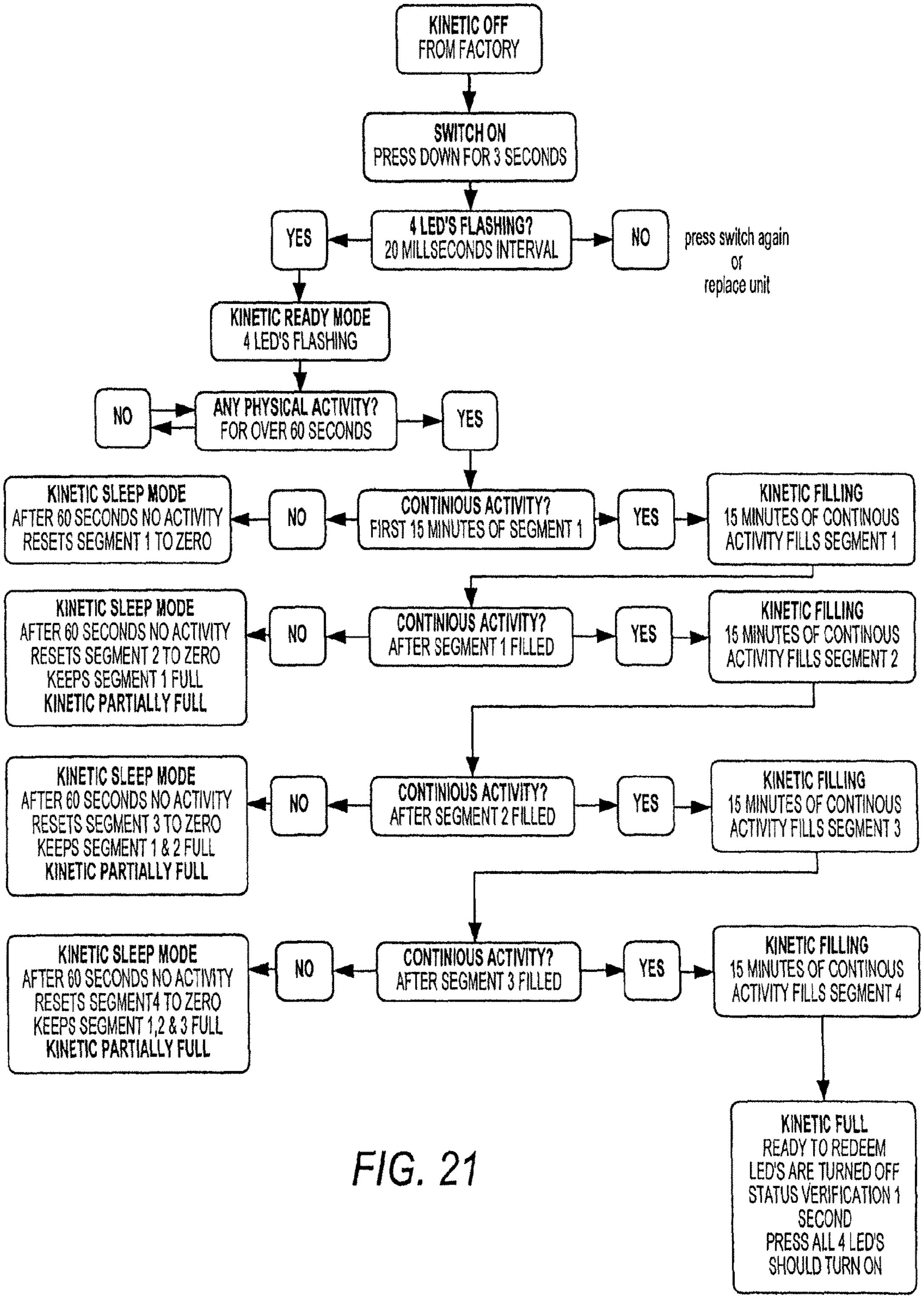

Finished Count Flash Win every xx seconds
Power Down after xx Seconds
Flash Live LED
< Start First Count
Check Motion Count
> First Count
Poll Motion Switch
Update Count
Wake Up the Processor
Flash Achievement Level
Check Time Between Counts
Power Up Unit
Reset Time Between Counts
Time < XX Seconds
Power Switch
If Time Between counts > xx seconds
Shut Down
Wait for Power Switch
Put Processor in Sleep Mode

FIG. 20



KINETIC OFF FROM FACTORY
SWITCH ON PRESS DOWN FOR 3 SECONDS
4 LED'S FLASHING? 20 MILLSECONDS INTERVAL
YES
NO
press switch again or replace unit
KINETIC READY MODE 4 LED'S FLASHING
ANY PHYSICAL ACTIVITY? FOR OVER 60 SECONDS
NO
YES
CONTINIOUS ACTIVITY? FIRST 15 MINUTES OF SEGMENT 1
NO
KINETIC SLEEP MODE AFTER 60 SECONDS NO ACTIVITY RESETS SEGMENT 1 TO ZERO
YES
KINETIC FILLING 15 MINUTES OF CONTINOUS ACTIVITY FILLS SEGMENT 1
CONTINIOUS ACTIVITY? AFTER SEGMENT 1 FILLED
NO
KINETIC SLEEP MODE AFTER 60 SECONDS NO ACTIVITY RESETS SEGMENT 2 TO ZERO KEEPS SEGMENT 1 FULL KINETIC PARTIALLY FULL
YES
KINETIC FILLING 15 MINUTES OF CONTINOUS ACTIVITY FILLS SEGMENT 2
CONTINIOUS ACTIVITY? AFTER SEGMENT 2 FILLED
NO
KINETIC SLEEP MODE AFTER 60 SECONDS NO ACTIVITY RESETS SEGMENT 3 TO ZERO KEEPS SEGMENT 1 & 2 FULL KINETIC PARTIALLY FULL
YES
KINETIC FILLING 15 MINUTES OF CONTINOUS ACTIVITY FILLS SEGMENT 3
CONTINIOUS ACTIVITY? AFTER SEGMENT 3 FILLED
NO
KINETIC SLEEP MODE AFTER 60 SECONDS NO ACTIVITY RESETS SEGMENT4 TO ZERO KEEPS SEGMENT 1,2 & 3 FULL KINETIC PARTIALLY FULL
YES
KINETIC FILLING 15 MINUTES OF CONTINOUS ACTIVITY FILLS SEGMENT 4
KINETIC FULL READY TO REDEEM LED'S ARE TURNED OFF STATUS VERIFICATION 1 SECOND PRESS ALL 4 LED'S SHOULD TURN ON

FIG. 21

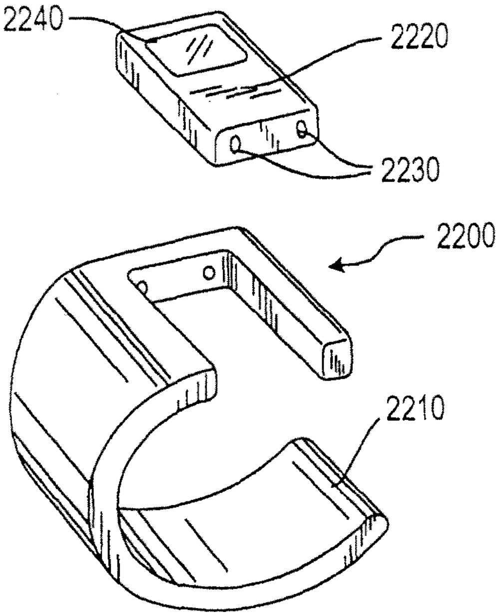


FIG. 22

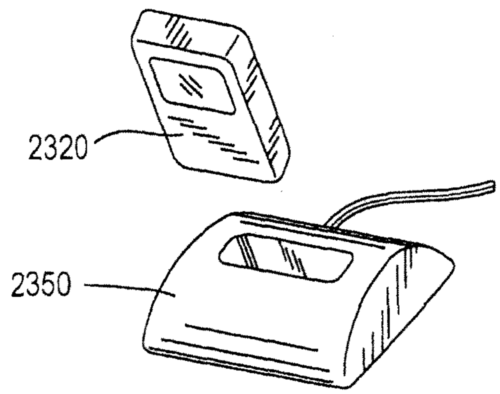


FIG. 23

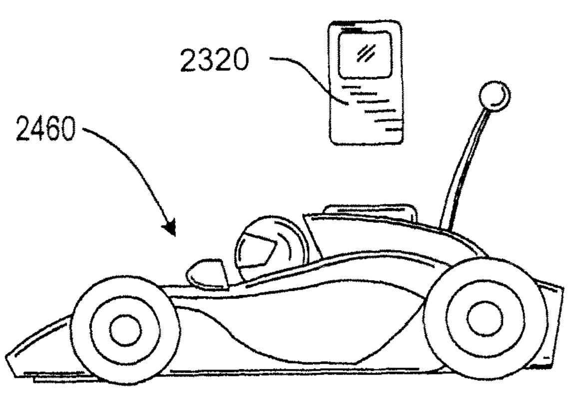


FIG. 24

SYSTEM AND METHOD FOR ACTIVATING A DEVICE BASED ON A RECORD OF PHYSICAL ACTIVITY

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/239,613, filed Sep. 26, 2008 (status: pending), which is a continuation-in-part application claiming the benefit of and priority to U.S. patent application Ser. No. 11/862,059, filed Sep. 26, 2007 (which issued as U.S. Pat. No. 8,177,260 B2 on May 15, 2012) and PCT International Application Serial No. PCT/IB07/03617, filed Sep. 26, 2007, each of which claim the benefit of and priority to U.S. Provisional Application Ser. No. 60/847,538, filed Sep. 26, 2006. This application also claims the benefit of and priority to U.S. Provisional Application Ser. No. 61/023,119, filed Jan. 24, 2008 and U.S. Provisional Application Ser. No. 60/975,411, filed Sep. 26, 2007. All of the preceding applications are hereby incorporated by reference herein in their entirety.

BACKGROUND OF THE INVENTION

The present application is directed to a system and method for encouraging physical activity and in particular a system and method for utilizing a coupon to indicate the achievement or completion of physical activity for a predetermined amount and/or predetermined period of time.

Obesity has taken a front seat in public discussions and media coverage. As a nation, we have been getting steadily heavier. The number of adults who are obese has increased dramatically. An estimated 300,000 deaths each year in the United States are attributed to obesity. The economic cost of obesity in the United States was approximately $117 billion in year 2000. Obesity has reached epidemic proportions in the United States, as well as worldwide. According to national data analyzed in 2002, it is estimated that 65% of Americans are now overweight or obese, and more than 61 million adults are obese.

Adults are not the only ones who have been getting heavier. The percentage of overweight children in the United States is growing at an alarming rate, specifically, it has more than doubled since the 1970s. Children are spending less time exercising and more time in front of the television, computer, or video-game consoles. According to the Center for Disease Control, 16% (or ~9 million) of American children are substantially overweight and the number is expected to grow by 20% over the next 5 years. Some states have childhood obesity rates as high as 25%. Children who lack exercise and proper nutrients in their diet are subject to an increased risk of potential serious health related problems including stunted growth, cognitive impairment, heart disease, diabetes and a range of other illnesses.

The United States Department of Health and Human Services recommends that children and teens be physically active for at least 60 minutes on most, if not all, days. It is recommended that adults engage in at least 30 minutes of moderate-intensity physical activity, above usual activity, on most days of the week. More than 60% of adults do not achieve the recommended amount of regular physical activity. In fact, 25% of the adults in the United States do not participate in any leisure time physical activity. Physical activity declines dramatically with age during adolescence. As such, nearly 50% of young people aged 12-21 are not active on a regular basis. Physical activity is important in preventing and treating obesity and is extremely helpful in maintaining weight loss, especially when combined with a healthy diet.

Exercise is one component of the equation to solve the problem of obesity. The real challenge is motivating individuals to participate in an exercise regimen or physical activity. People's behavior must change and they must lead a lifestyle of physical activity. Corporations have become sensitive to the perception that they are socially responsible. As such, corporations strategically advertise and promote their contributions towards a healthy community and encourage physical activity. Numerous fast food restaurants have dramatically altered their menus to incorporate healthy foods thereby promoting the importance of healthy lifestyles and physical fitness.

Exercise, while rewarding in numerous ways, offers little incentive or motivation for individuals to continue to exercise and stay physically fit. Most corporations today rely on monetary coupons or rebates to encourage the purchase of a particular product or service. In the year 2000 over 330 billion coupons were distributed with approximately 4.5 redeemed for a total consumer savings of $3.6 billion. Overall, 77.3% of people use coupons.

Issuance of rewards or incentives to encourage, motivate, or promote additional physical activity or exercise is nothing new. For instance, U.S. Pat. No. 6,585,622 as well as U.S. Published Application Nos. 2005/0102172; 2003/0065561; 2002/0077219 all disclose systems in which rewards are earned based on user participation in physical activity or exercise. Rewards or points are accumulated and may be redeemed at a later point in time. Such systems require the establishment of an infrastructure so that the physical activity of the user may be monitored and the rewards of incentive points issued. In part due to the expense associated with employing such an infrastructure, these systems and methods are best suited for monitoring participation in physical activity or exercise over an extended period of time. Irrespective of the accumulation and tabulation of intangible rewards or points as they are earned over a period of time, such a protracted process is better suited for adults rather than children or teenagers who have a shorter attention span which requires more immediate gratification in today's fast paced society.

It is therefore desirable to develop a new interactive physical coupon, whereby after engaging in physical activity for a predetermined amount and/or predetermined period of time the coupon is activated and immediately redeemable providing the user with immediate satisfaction.

SUMMARY OF THE INVENTION

The present application is directed to an interactive coupon redeemable by the holder after having participated in physical activity for a predetermined period of time.

The application relates to a kinetic coupon for encouraging participation in physical activity. Initially, the kinetic coupon may be inactive when dispensed to the user. While in possession of the kinetic coupon the user participates in physical activity that is monitored by circuitry in the coupon. The circuitry determines when the user's participation in physical activity exceeds a predetermined threshold, e.g., a predetermined amount and/or predetermined period of time, After participating in physical activity that exceeds the predetermined threshold, the kinetic coupon is validated and signified to the user that it is now redeemable.

The application comprises a coupon that detects physical activity of a user using a motion detector. The motion detector

may use any one of a variety of technologies such as chemical motion detectors, mechanical motion detectors, or electrical motion detectors.

A chemical motion detector according to the present application may comprise one or more chemicals which, when mixed, indicate to a user that the threshold of activity has been reached. The chemicals may be included in various reservoirs or indicator wells which mix upon physical activity and movement of the motion detector. The chemicals may also be mixed using micropumps which are powered by movement of the motion detector and dispense the chemicals from one or more reservoirs. In a further embodiment, a piezoelectric device powered by physical activity may be used to power the micropumps. The micropumps may be configured to function only upon a certain level of physical activity such that minor movements of the motion detector do not drive the micropumps.

In another embodiment, a chemical motion detector according to the present application may comprise one or more chemical solutions that react to the sweat, pH level of biological cues, or chemicals released by or through a user's skin during and after physical activity.

In another embodiment, a chemical motion detector according to the present application may comprise one or more chemicals that are microencapsulated in small spheres that burst upon physical activity. An abrasive agent may be provided adjacent to the spheres to assist in the rupture of the spheres.

A mechanical motion detector according to the present application may comprise a number of different configurations. In one embodiment, the motion detector comprises a pendulum which moves upon physical activity of the user and causes the rotation of a ratchet gear. Once the ratchet gear has been moved a sufficient number of times, the user is presented with the indicator. Another embodiment of a mechanical motion detector to be used with the present application is a magnetic switch in which a metal ball is held in place using magnetic attraction. Physical activity of the user will force the metal ball to move and short against a contact, which is detected and used to determine when the threshold of physical activity has been reached.

Another embodiment of a mechanical motion detector comprises a conductive tube in which a conductive object such as a metal ball is disposed. A spring inside the conductive tube maintains the ball apart from a contact at the end of the tube. Motion such as physical activity of the user causes the ball to compress the spring and short against the contact at the end of the tube, which is registered by a circuit which determines when the predetermined threshold of activity has been reached.

In a further embodiment of a mechanical motion detector which may be used with the present application, a conductive element such as a ball is disposed in a bounded area on a conductive plate and surrounded by a conductive wall or conductive posts. The wall or posts are separated from the conductive plate such that the ball will close a circuit between the wall or posts and the plate when the ball touches the wall or posts. Upon physical activity of the user, the ball moves inside the bounded area and closes a circuit between the wall or posts and the plate whenever it touches them both. The bounded area may be flat and elongated in a certain direction to detect only one range of motion. The bounded area may also be a sphere in order to detect motion in every direction. The different posts may register different signals with the circuitry so that the present application may detect a predetermined threshold of various different types of physical activities which cause different motions of the motion detector. In some embodiments, a dampening device surrounds the ball in order to eliminate the detection of minor movements that do not constitute physical activity which the present application seeks to detect.

Another embodiment of a mechanical motion detector comprises a conductive pin, wire, or ribbon which may have a conductive weight on the free end. Spaced from the weight in various different directions are contact points which close a circuit upon contact with the weight. While the motion detector is not moving, the weight is not contacting any other surface, but physical activity will cause the weight to move and contact one or more contact points disposed a predetermined distance from the weight.

The coupon according to the present application has an indicator which indicates to the user when a certain threshold of physical activity has been reached. The indicator may be a change in color of the coupon, the appearance of an image or message on the coupon, a visual indicator such as a light emitting diode, or a sonic indicator.

Once the predetermined threshold of physical activity has been detected by the coupon, the coupon may be redeemed. In one embodiment, the coupon may be redeemed by bringing the coupon to a location such as a retail store or restaurant which accepts the coupon in exchange for free or discounted goods and/or services. In another embodiment, the coupon may be redeemed on an interactive web site by, for example, entering a unique code from the coupon into the web site. The unique code may be electronically revealed on a display such as, for example, a liquid crystal display or a series of light emitting diodes. The unique code may also be permanently printed on the coupon or printed on the coupon in a way that reveals all or a portion of the unique code once the predetermined threshold of physical activity has been reached. The coupon may be redeemed for users to earn free or discounted goods and/or services. In a further embodiment, the coupon may be redeemed for points or virtual currency which may be used for online goods, services, or games.

In one embodiment, the coupon is a single-use product that may be discarded upon redemption. In another embodiment, once the coupon has reached the predetermined threshold of physical activity and redeemed, it may be reset so that it may be used again. In this embodiment, the vendor who issued and collected the coupon may reset the coupon for repeated distribution. In one embodiment, the vendor may be a computer system that automatically resets the coupon without any user interaction. In another embodiment, a single user may retain the coupon and redeem the coupon for rewards each time the predetermined threshold of physical activity has been reached.

An embodiment covers a redeemable coupon comprising a housing, a motion detector coupled to the housing, wherein the motion detector detects an amount of motion of the coupon, and an indicator coupled to the motion detector, wherein the indicator is activated by the motion detector upon detecting the amount of motion.

In an embodiment the coupon may be redeemed, for example, via an electronic network. The electronic network may be, for example, the Internet or a wireless communication network. The coupon may be redeemable for items, such as, for example, money, points, prizes or an item relating to an electronic game, such as, for example. at least one of an avatar, life, strength, a weapon, a potion, money, health, ammunition, special power, food, an accessory, a pet, an article of clothing, a clue, and a key.

In an embodiment, the motion may be monitored, for example, during a predetermined time interval, or from a first predetermined point in time until a second predetermined

point in time. Additionally, the at least one of the first predetermined point in time and the second predetermined point in time may be a preset date. Alternatively, at least one of the first predetermined point in time may be an activation of the motion detector and/or the second predetermined point in time may be determined from the first predetermined point in time and a predetermined time interval.

In an embodiment the redeemable coupon may further comprise computer programmable code including instructions that implement an electronic game.

In an embodiment the information indicated by the indicator may correspond to at least one of a point and a reward based on a level of motion detected by the motion detector.

In an embodiment a user may interact with an online game using the redeemable coupon. In another embodiment the indicator may present a code. In yet another embodiment the redeemable coupon may be used to interact with an online game by entering the code from the indicator. In one or more of the prior embodiments, the user may be rewarded upon detection of a predetermined level of motion by the motion detector. The reward may be at least one of money, a prize, an game item and points. The game item may be at least one of an avatar, life, strength, a weapon, a potion, money, health, ammunition, special power, food, an accessory, a pet, an article of clothing, a clue, and a key.

In an embodiment a user may be rewarded based on a level of motion detected by the motion detector. In another embodiment the user may be rewarded based on an amount of motion detected by the motion sensor.

In an embodiment the redeemable coupon may be provided together with a product offered to consumers. The redeemable coupon may comprises a packaging for the product or a label for the product.

In an embodiment the motion detector may be decoupled from the housing. In one or more of the prior embodiments the housing may be a wearable object. The wearable object may be selected from the group including a bracelet, anklet, necklace, headband, hat, scarf, glove, clothing, footwear, pin, clip, eyewear, belt and neckwear.

In an embodiment a memory may be coupled to the motion detector, wherein the memory stores information from the motion detector. The information may include the amount of motion detected.

One or more of the previous embodiments may further comprise an electronic device, wherein at least one of the motion detector is decoupled from the housing and coupled to the electronic device. The motion detector may activate at least one feature of the electronic device based on the amount of motion detected prior to decoupling. The electronic device may be at least one of a game, toy, game controller, computer interface device, cell phone, mobile data communication device, microprocessor or computer. The motion detector may be coupled to an electronic game controller. In an embodiment the coupon may further comprise an electronic device, wherein the memory is decoupled from the motion detector and coupled to the electronic device. The electronic device may be at least one of a game, toy, game controller, computer interface device, cell phone, mobile data communication device, microprocessor or computer. In one or more of the prior embodiments the electronic device may be usable for a period of time corresponding to the amount of motion detected. In one embodiment the coupon may further comprise a base station, wherein at least one of the motion detector and the memory is coupled to the base station. The base station may be in communication with a processing arrangement. The processing arrangement may control an interactive game.

In one embodiment at least one of the motion detector and the memory may enable a feature of the electronic device.

In an embodiment the coupon may further comprise a transmitter, wherein the transmitter may be used to communicate with a wireless network. In an embodiment the coupon may further comprise an electronic device, wherein the memory communicates with the electronic device using the transmitter.

In one or more of the embodiments the motion detector may distinguish between levels of physical activity. Alternatively or additionally, the motion detector may distinguish between types of physical activity. The indicator may comprise a plurality of indicators. Each of the plurality of indicators may correspond to a type of physical activity.

In an embodiment the indicator may be a code which may be used for redeeming the coupon from a remote location. The coupon may be redeemed via a web site. The coupon may be redeemed via a portable electronic device.

In an embodiment the motion detector may activate a plurality of indicators upon the attainment of a plurality of predetermined limits. The motion detector may be adapted to deactivate the indicator when a predetermined threshold of inactivity is reached.

In one or more of the above embodiments the coupon may be coupled to a bracelet. The coupon may be formed of flexible material. In one or more of the above embodiments at least one of the motion detector and indicator may be reset or resettable.

An embodiment covers a method of providing an incentive for a user to exercise comprising providing the user with a coupon to be coupled to the user, monitoring the motion of the user with a motion sensor included in the coupon, and activating the coupon when the motion sensor has detected a predetermined amount of motion such that the coupon becomes redeemable by the user. The method may further comprise indicating to the user when the motion sensor has detected a predetermined amount of motion. The method may also comprise redeeming the coupon. The coupon may be redeemed, for example, via an electronic network. The electronic network may be, for example, the Internet or a wireless communication network. In an embodiment the coupon may be redeemable for money, points, prizes or an item relating to an electronic game. In an embodiment the item may be at least one of an avatar, life, strength, a weapon, a potion, money, health, ammunition, special power, food, an accessory, a pet, an article of clothing, a clue, and a key.

In an embodiment the motion may be monitored, for example, during a predetermined time interval or from a first predetermined point in time until a second predetermined point in time. In an embodiment at least one of the first predetermined point in time and the second predetermined point in time may be a preset date. In an embodiment at least one of the first predetermined point in time may be an activation of the motion sensor. In an embodiment the second predetermined point in time may be determined from the first predetermined point in time and a predetermined time interval.

In an embodiment the coupon may comprise a game. An embodiment may further comprise issuing at least one of a point and a reward to the user based on a level of motion monitored by the motion sensor. An embodiment may further comprise the user interacting with an online game using the coupon. Another embodiment may further comprise the coupon presenting a code. An embodiment may further comprise interacting with an online game by entering the code provided by the coupon. An embodiment may further comprise rewarding the user upon detection of a predetermined level of motion

by the motion sensor. The reward may be at least one of money, a prize, a game item and points. The game item may be at least one of an avatar, life, strength, a weapon, a potion, money, health, ammunition, special power, food, an accessory, a pet, an article of clothing, a clue, and a key. An embodiment may further comprise rewarding the user based on a level of motion detected by the motion sensor. An embodiment may further comprise rewarding the user based on an amount of motion detected by the motion sensor.

In an embodiment the coupon may be provided with a product offered to consumers. The coupon may comprise a packaging for the product. The coupon may comprise a label for the product.

An embodiment further comprises decoupling the motion sensor from the coupon. In an embodiment the coupon may be a wearable object. The wearable object may be selected from the group including a bracelet, anklet, necklace, headband, hat, scarf, glove, clothing, footwear, pin, clip, eyewear, belt and neckwear.

In an embodiment the motion sensor may include a memory that stores information from the motion detector. The information may include the amount of motion detected. An embodiment may further comprise coupling the motion sensor to an electronic device. An embodiment may further comprise activating at least one feature of the electronic device based on the amount of motion detected prior to decoupling. The electronic device may be at least one of a game, toy, game controller, computer interface device, cell phone, mobile data communication device, microprocessor or computer. An embodiment may further comprise coupling the motion sensor to an electronic game controller. An embodiment may further comprise coupling the memory to the electronic device. The electronic device may be at least one of a game, toy, game controller, computer interface device, cell phone, mobile data communication device, microprocessor or computer. The electronic device may be usable for a period of time corresponding to the amount of motion detected.

An embodiment may further comprise coupling at least one of the motion sensor and the memory to a base station. An embodiment may further comprise communicating between the base station and a processing arrangement. Another embodiment may further comprise controlling an interactive game from the processing arrangement. An embodiment may further comprise enabling a feature of the electronic device by at least one of the motion sensor and the memory. Another embodiment may further comprise enabling a feature of the electronic device by at least one of the motion sensor and the memory. An additional embodiment may further comprise communicating with a wireless device using a transmitter. Another embodiment may further comprise communicating between the memory and an electronic device using the transmitter.

In an embodiment the predetermined amount of motion may be based on a level of physical activity. In an embodiment the motion sensor may distinguish between types of physical activity. The predetermined amount of motion may comprise a plurality of predetermined amounts of motion. Each of the plurality of predetermined amounts of motion may correspond to a type of physical activity.

In an embodiment the coupon may be activated by providing a code which may be used for redeeming the coupon from a remote location. In an embodiment the coupon may be redeemed via a web site. In another embodiment the coupon may be redeemed via a portable electronic device.

Another embodiment further comprises activating the coupon upon the attainment of a plurality of predetermined limits. An embodiment further comprises deactivate the coupon when a predetermined threshold of inactivity is reached.

In an embodiment the coupon may be coupled to a bracelet. In an embodiment the coupon may be formed of flexible material. In an embodiment at least one of the motion detector and indicator may be reset or resettable. Another embodiment may further comprise decoupling the motion sensor from the coupon.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features of the present application of the present application will be more readily apparent from the following detailed description and drawings of illustrative embodiments of the application wherein like reference numbers refer to similar elements throughout the several views in which:

FIG. **1** is a enlarged perspective view of the exemplary kinetic coupon in accordance with the present application;

FIG. **2** is an exemplary kinetic coupon in accordance with the present application shown being worn on different parts of the body;

FIGS. **3**A and **3**B are front and side views, respectively, of an exemplary device employing chemical technology for monitoring the extent of participation in physical activity or movement by the user;

FIG. **3**C is a front view of the device in FIGS. **3**A and **3**B with the membrane deformed;

FIG. **4** is a schematic diagram of an exemplary device employing mechanical technology for monitoring the extent of participation in physical activity or movement by the user;

FIG. **5** is a schematic diagram of an exemplary device employing electrical technology for monitoring the extent of participation in physical activity or movement by the user; and

FIG. **6** is an exemplary flow chart of the use of the kinetic coupon in accordance with the present application.

FIGS. **7**A and **7**B depict one embodiment of a motion-activated coupon according to the present application.

FIG. **8**A shows a motion sensor in which a magnetic ball is held by magnetic attraction between contacts in a tube, in accordance with one embodiment of the present invention.

FIG. **8**B shows a motion sensor having a conductive object and a coil inside a conductive tube, in accordance with one embodiment of the present invention.

FIG. **8**C shows a motion sensor having a conductive ball housed in a conductive tube between two springs, in accordance with one embodiment of the present invention.

FIG. **9** shows a dual-axis motion sensor having a ball in a cross-shaped channel, in accordance with one embodiment of the present invention.

FIG. **10** shows a single-axis motion sensor in which a conductive flat spring has one end affixed to a conductive member with a weight on the other end to amplify detected motion, in accordance with one embodiment of the present invention.

FIG. **11** shows a dual-axis motion sensor in which a single conductive flat spring is bent to form an angle between 1 and 90 degrees and in which each end of the conductive flat spring incorporates a weight to amplify detected motion, in accordance with one embodiment of the present invention.

FIG. **12** shows a motion sensor having a dual-axis or balanced pendulum motion detector in which a pendulum pivots at one end and contains a weight at the other, and in which two balanced hair pin springs are symmetrically located around a long axis of the pendulum, in accordance with one embodiment of the present invention.

FIG. **13** shows a three-axis motion sensor in which a conductive spring wire is affixed to a mounting plate at one end and has a weight at the other end that protrudes through a conductive hoop, in accordance with one embodiment of the present invention.

FIG. **14** shows a motion sensor having raised conductive ring members arranged equidistant from a center point and mounted on a platform, with a movable puck located inside the raised conductive ring members, in accordance with one embodiment of the present invention.

FIG. **15**A shows a motion sensor having a conductive element such as a ball, a dampening element such as a foam ring, and a conductive ring disposed on a substrate, in accordance with one embodiment of the present invention.

FIG. **15**B shows the motion sensor of FIG. **15**A with the conductive ring surrounding an inner conductor, in accordance with one embodiment of the present invention.

FIG. **15**C shows a cross-section of the motion sensor of FIG. **15**A with the ball resting on the inner conductor and held apart from the conductive ring by the foam ring, in accordance with one embodiment of the present invention.

FIG. **15**D shows the cross-section of the motion sensor of FIG. **15**A with motion causing the ball to be forced against the foam ring so as to deform the foam ring and form a circuit between the inner conductor and the conductive ring, in accordance with one embodiment of the present invention.

FIG. **15**E shows the cross-section of the motion sensor of FIG. **15**A in which the inner conductor has channels, holes, or protuberances which inhibit free movement of the ball, in accordance with one embodiment of the present invention.

FIG. **16** shows a motion sensor in which a conductive element such as a ball is disposed in a dampening element such as a foam ring which is placed inside a number of conductive posts on a substrate, in accordance with one embodiment of the present invention.

FIG. **17** shows a motion sensor in which a conductive pin has a weight coupled to its end with the weight surrounded by a conductive member and/or conductive plate, in accordance with one embodiment of the present invention.

FIG. **18**A shows a motion sensor in which a conductive pin has a weight at its end with the weight surrounded by conductive posts and positioned above a conductive plate, in accordance with one embodiment of the present invention.

FIG. **18**B shows a side-view of the motion sensor of FIG. **18**A, in accordance with one embodiment of the present invention.

FIG. **19** depicts one embodiment of a coupon according to the present application coupled to a wearable device.

FIG. **20** depicts a flow diagram of one embodiment of a method of conserving power according to the present application.

FIG. **21** depicts a flow diagram of a method according to the present application.

FIG. **22** depicts an embodiment of a device according to the present invention with a removable component that records physical activity detected by the device.

FIG. **23** depicts the removable component shown in FIG. **22** as inserted into a base with a communication cable.

FIG. **24** depicts the removable component showing in FIG. **22** being inserted into a toy.

DETAILED DESCRIPTION

The present application is directed to an interactive or "kinetic" coupon that is a physical device which is redeemable, activated or validated only after the user has participated in movement or physical activity of a predetermined amount and/or for a predetermined period of time. Referring to FIG. **1**, the kinetic coupon **100** has a housing **115** in which is enclosed components for monitoring the extent of physical activity or movement by the user and activating an indicator to signify to the user when the kinetic coupon is redeemable, activated or validated. A display **120** such as, for example, a light emitting diode (LED), liquid crystal display (LCD) or other display device is provided for display of some type of indicia indicating when the physical activity exceeds a predetermined threshold, i.e., a predetermined amount and/or predetermined period of time. The indicator may simply be a color indicator (e.g., change from colorless to a color, change of color or change from opaque to transparent to reveal some indicia otherwise not previously visible). For instance, after participating in physical activity for a predetermined period of time, a green color may be indicated on the display **120**. Alternatively, written indicia may be observed in the display **120**. Any desired alphanumeric word or message may be displayed. In one embodiment, the written indicia may display some sort of encouragement such as "Keep Going", "Don't Stop" before the predetermined time period has expired in which the user has participated in physical activity or movement. Once the wearer has participated in physical activity for the predetermined threshold the indicia is activated to reflect the redeemable value of the coupon and/or perhaps the location at which the coupon is to be redeemed. By way of example, upon engaging in physical activity or movement for the predetermined period of time, the display **120** may read "Free Frisbee" and the name of the participating vendor from whom the toy may be redeemed. The kinetic coupon may alternatively, or in addition to a visual indicator, include an audible alarm and associated circuitry for producing an audible alarm. Upon the engagement of physical activity that exceeds the predetermined threshold, the kinetic coupon will produce or generate an audible sound to inform the wearer that the coupon may now be redeemed. Such audible alarm may be a beep, melody, word, phrase or instructions as to how to go about redeeming the value of the coupon.

The coupon may be redeemable on an interactive web site for free or discounted goods and/or services. The coupon may, for example, display a code when the predetermined threshold has been reached. The coupon may also display a code which will only be accepted by a vendor once the coupon has issued an indicator that the threshold level of physical activity has been reached. The user may then enter the code into the web site to be redeemed. The coupon may also be redeemed for points or virtual currency in an online game or in an online gaming environment. The points or virtual currency may be used to purchase additional games. In some games, the coupon may be redeemed for rewards specific to that game such as, for example, special playable characters, special playable levels, costumes for a character, character energy or health, or playable items that that may be branded with the logo of the entity that issued the bracelet. For example, in a car racing game, the user may be able to redeem the coupon for a playable car that is branded with a vendor's logo.

In one embodiment, the coupon may communicate with a computer system which includes a computer game. The user may participate in the game by achieving a predetermined level of physical activity for an extended period of time. In one embodiment, the game comprises a virtual character such as a virtual pet whose health and progress through a game is determined by the physical activity of the user as measured by the coupon.

Kinetic coupon **100** may be secured about a part of the body, for example, by a band or strap **110**. FIG. **2** shows

several exemplary positions of the kinetic coupon **100** worn on the body **210**, e.g., about the wrist **205** or ankle **215**. Other parts of the body **210** may be chose such as, but not limited to, the head, earlobe, neck, arm, finger, leg, toe, or waist. As shown in FIG. **1**, the strap **110** may also include a securing device **105**. The securing device **105** may be, but need not necessarily be, releasable such as hook-n-eye, VELCRO™, a buckle, a snap or a clasp. In the case that the securing device **105** is not releasable, then the strap may be broken or torn after use and discarded either alone or with the housing **115** and components disposed therein. Yet another variation of the present application would eliminate the securing device **105** altogether whereby the strap would be made of a material such as a thin metal or plastic band that in a relaxed state is wound into a coil, but upon the application of a force may be stretched out substantially straight. After being positioned about a portion of the body the force exerted on the band is removed allowing it to return to its relaxed state and substantially conform about a part of the user's body. The strap may be custom designed and printed, as desired, for instance, to identify a corporate name and/or promotional item or an advertiser.

Alternatively, the strap **110** itself may also be eliminated and the kinetic coupon **100** releasable secured directly to the wearer's body or clothing via an adhesive strip, pin or other device. This alternative embodiment is particularly well suited for placement of the kinetic coupon on rather than about a part of the body such as depicted in FIG. **2** by coupon **220** worn on the wearer's chest. Instead of being worn on or about the user's body or clothing, the kinetic coupon may simply be held in the user's hand.

As previously mentioned the coupon **100** includes components for indicating when the user's participation in physical activity or movement exceeds a predetermined threshold, e.g., a predetermined amount and/or predetermined period of time, required to activate or validate the coupon. The kinetic coupon may be designed to require either continuous or non-continuous physical activity or movement. Functionality for monitoring the extent of the user's participation in physical activity or movement may be achieved using chemical, mechanical and electrical technology either exclusively or in combination thereof. It is advantageous to minimize the cost of manufacture and overall size when designing the components for monitoring the extent of participation in physical activity or movement by the user. An illustrative example of a system for monitoring the extent of user's participation in physical activity or movement utilizing each of the three different technologies will be described, however, alternative devices such as piezoelectric devices or pedometers are contemplated and within the intended scope of the present application.

The first method to be addressed employs chemical technology whereby one or more chemicals when mixed together activate an indicator that signifies to the user participation in movement for at least a predetermined threshold, e.g., predetermined amount and/or predetermined time period. Referring to FIGS. **3**A and **3**B, indicator wells **305** are filled with a chemical indicator that is activated when mixed with fluid from a reservoir **310**. In the illustrative example shown, the coupon includes three indicator wells **305**, each having three indicator apertures **325**, wherein each indicator aperture represents a different indicator (e.g., different color or indicia such as a letter or number). An impervious membrane **315** covers the surface of the device and is sealed around a pump **320** to form a vacuum. The pump **320** such a micro-pump is used to dispense fluid from reservoir **310**. A fluid is selected based on such factors as its potential corrosive effects and viscosity to pass through the pump. In the exemplary embodiment three pumps **320** are shown, one associated with each well indicator **305**. The application may be modified, as desired, to vary the number of indicator wells, indicator apertures and/or pumps.

An external force such as a motor or piezoelectric device may be used to drive the micro-pump. However, the use of a motor or piezoelectric device disadvantageously requires a power source that contributes to both the overall cost of manufacture and footprint of the integrated circuit. In a preferred embodiment, the use of a power source is eliminated altogether and instead the micro-pumps are driven by an oscillating membrane that acts as a piston. The user's motion thereby supplies the necessary force to drive the micro-pump. Accordingly, a predetermined minimum threshold level of physical activity or movement may be required to drive the micro-pump. Some physical activity or movement may be so inconsequential as to be insufficient to drive the micro-pump. Some physical or movement may be so inconsequential as to be insufficient to drive the micro-pump. As the user moves, the mass of the fluid in pumping well **350** causes the membrane **315** to vibrate or oscillate and deform, as shown in FIG. **3**C. The pumping action of mass or magnet **340** may be enhanced by utilizing a changing magnetic field or a fluctuating mass. Specifically, as shown in FIG. **3**C a magnetic field is created by the displacement of a magnet **340** with respect to an attracting material **345** such as steel or other magnetic material disposed proximate the pump **320**. The attracting material **345** shown in FIG. **3**C is configured in the shape of a metal ring. in operation, the user's motion causes the membrane **315** to vibrate or oscillate by the mass of the fluid flowing into the pumping well **350** from reservoir **310** resulting in an initial displacement of magnet **340**. As the magnet **340** approaches the metal ring **345** the attraction of magnetic forces assist the suction of fluid from the reservoir **310** into the pump well **350**. Gravity and motion forces the fluid into the indicator wells **305**.

Reducing channels or reserve flow restrictors **330**, **335** are preferable used to create a unidirectional flow of fluid from the reservoir **310** to each of the indicator wells **305**. As the mass or magnet **340** is displaced in a positive y-direction a vacuum forces liquid to flow from the reservoir **310** into the pumping well. Micro-pump **320** provides metered output based on the type of movement or physical activity. The mass of magnet **340** is selected based on different activity levels. The orifice of the flow restrictors may be adjusted to accommodate a wide variety of flow rates and fluids. Fluids stored in reservoir **310** may be neutral, acidic or alkaline. The indicator in wells **305** may be a solid, fluid, gas or some combination thereof which when it mixes with the fluid from reservoir **310** is activated. In one embodiment the indicator wells activate the indicator immediately upon contact with fluid dispersed from the reservoir, irrespective of the amount of fluid. However, an alternative embodiment provides for activation of the indicator by a predetermined amount of fluid from the reservoir passing into the indicator well. This latter embodiment may be employed to signify that a period of time for participation by the user in physical activity or movement has expired. Exemplary indicators such as fluids, gels or paper that may be used include halochromic chemical compound that produce changes in compounds such as Thymol blue, Methyl red and Indigo carmine. Another class of fluid is Amylose in starch which can be used to produce a blue color in the presence of iodine. The iodine molecule slips inside of the amylose coil. Iodine is not very soluble in water, therefore the iodine reagent is made by dissolving iodine in water in the presence of potassium iodide to produce a soluble linear

triiodide ion complex. The triiodide ion slips into the coil of the starch creating a blue-black color.

In one embodiment, the coupon comprises one or more chemical solutions that react to motion, sweat, and/or pH level of the user's skin during and after a physical activity. The chemical solutions may cause a portion of the coupon to change from one color to another. The chemical solutions may also transform an opaque overlay to a transparent overlay to reveal a layer of printed information below the layer. One example of this embodiment is depicted in FIGS. **7**A and **7**B. Coupon **700** has a first layer **710** which may contain a message or image and a second layer **720** with an overlay **730** that will transform from opaque to transparent upon the physical activity that activates the chemical solutions. The transparent window will then allow the user to view the message on the first layer **710**.

In one embodiment, the coupon comprises two or more chemicals that react to movement of the coupon. One or more of the chemicals may be microencapsulated in small spheres and react to the second part of the solution that has an abrasive. The abrasive, with time and physical agitation, will break the encapsulated spheres and mix the two chemicals. One or more of the solutions will then change from one color to another or from an opaque overlay to a transparent overlay to reveal a layer of printed information below the overlay.

In one embodiment, the coupon comprises two gels which begin mixing when a seal separating them is broken. The physical agitation from the user will mix the two gels over a predetermined amount of time. Once the two gels have sufficiently mixed, they will then change from one color to another or from an opaque overlay to a transparent overlay to reveal a layer of printed information below the overlay.

The next methodology to be discussed is use of the mechanical technology whereby mechanical components are displaced by forces generated by or derived from the user's motion to indicate when the user has engaged in physical activity or movement for a predetermined threshold, e.g., a predetermined amount and/or predetermined period of time. A pendulum is employed that swings when the user moves. Guides **445** serve as an escapement mechanism to restrict movement to a single direction. FIG. **4** is an exemplary assembly **400** that includes a ratchet gear **405** rotatably mounted on a base **440**. A weight **415** freely supported by a level or arm **430** serves as a pendulum. The user's motion is imparted to weight **415** which, in turn, displaces the lever or arm **430** engaging a tooth of the ratchet gear **405** causing it to rotate. A rubber band **420** produces a balancing or restoring force. Hinge **425** allows the lever or arm **430** to pivot between a downward stroke position in which it engages a tooth of the ratchet gear **405** and another position a predetermined distance clear of the gear when the restoring force generated by the rubber band **420** pulls the arm back to its original position. Indicator apertures **410** may be provided to enable a mark to be visually observed by the user to signify when the user has engaged in a predetermined amount of physical activity or movement.

In the case of the present inventive kinetic coupon being utilized as an incentive for children to engage in physical activity to promote a healthier lifestyle, it is often desirable to ignore or disregard physical activity or movement by the user that is inconsequential or insignificant so as not to contribute towards the issuance or earning or rewards or points. Therefore the present application may be designed so that the motion exerted by the user is not recorded until it exceeds a predetermined threshold level. There are numerous methods in which said functionality may be accomplished an example of which will be described in further detail.

Referring once again to the mechanical assembly shown in FIG. **4**, motion exerted by the user is not recorded until it overcomes or exceeds a counterbalancing static force exerted on the ratchet gear **405**. This counterbalancing static force may be produced by a tension spring **435**, a magnet or other device. Rotation of the ratchet gear **405** is restricted by a restricting arm **450** which is pivotally mounted to base **440**. The tension spring **435** is connected between the base and restricting arm **450**. When the user's motion overcomes or exceeds the counterbalancing static force produced by the tension spring physical activity or movement is recorded.

In one embodiment, the coupon comprises a kinetic device as a sensor which comprises a magnetic switch. The magnetic switch may include a conductive object such as, for example, a metal ball which is held in place in an area by magnetic attraction. If the force is strong enough the object will overcome the magnetic force of the object, which will move to either end of the area and short against two contacts at the boundaries of the area. The shorted contacts may be periodically sampled to assess physical activity. FIG. **8**A depicts one example of this a motion sensor **800** according to this embodiment in which the magnetic ball **810** is held by magnetic attraction between the contacts **830** in the tube **820**.

In one embodiment, a coupon comprises a microprocessor which periodically samples the contacts in a motion detector to determine when contact has been made. The sample rate may be adjusted by adjusting the internal timer. The microprocessor may also be set to turn on when there is a transition on the contacts and turn off when no motion is detected to conserve power. The battery may be shipped in the unit. A power switch will trigger the unit on. The power can be automatically turned off by the processor or can be enabled for a preset duration. A capacitor is used to keep the power switch on. Over time the voltage on the capacitor is bled off with a high value resistor. If the processor wishes to stay alive the processor can recharge the voltage on the capacitor.

In one embodiment as depicted in FIG. **20**, the software on the microprocessor has two main loops that run. The first loop is the power loop. In this loop the unit is powered up from the power switch. The unit then processes the second loop, which tracks movement. When movement is not detected the unit within a predetermined number of seconds of use it will go back to sleep. The unit will wake up if motion is detected on the motion detect switch or the power switch is depressed.

In one embodiment, the coupon includes a motion sensor composed of a conductive tube inside of which resides a conductive object such as a ball and a coil. FIG. **8**B depicts a motion sensor **800** according to one example of this embodiment. One end of the tube **820** contains an electrical contact **830** insulated from the tube. A coil **840**, compression spring, or other compressible, non conductive material rests on the insulted portion of the electrical contact **830** located in the end of the insulted tube **820** and holds the conductive ball **810** from the end of the conductive tube **820**. Upon sensing motion, the ball **810** deflects inside tube **820** in the general direction of the motion. This compresses the spring **840** and, if the motion is of sufficient magnitude, causes the ball **810** to come in contact with the contact **830** at the end of the conductive tube **820**. Coming in contact with the electrical contact **830** in the end of the tube **820** causes an electrical circuit to be made. This circuit signal is interpreted by control electronics indicating that motion has occurred. The circuit signal may include a electronic circuit that incorporates algorithms capable of detecting individual deflections and interprets the inputs to correspond to the use, orientation and numeric quantity of deflections detected. The electronics interpret the information and send the results to a storage or enunciation

device which may include a display such as, for example, liquid crystal display, light emitting diode display or other means to store or communicate the resulting information to a user.

In one embodiment, the coupon comprises a spring-loaded ball and multiple contact tube motion detector. The motion sensor may be composed of a conductive tube inside of which resides a conductive ball. Each end of the tube contains an electrical contact insulated from the tube. Two coil compression springs or other compressible material rest on the insulated portion of the electrical contact located in the end of the insulated tube and hold the conductive ball equidistant from the ends of the conductive tube. Upon sensing motion, the ball deflects inside tube in the general direction of the motion. This compresses the spring and, if the motion is of sufficient magnitude, causes the ball to come in contact with the contact at the end of the conductive tube. Coming in contact with the electrical contact in the end of the tube causes an electrical circuit to be made. This circuit signal is interpreted by control electronics indicating that motion has occurred. One example of this embodiment is depicted in FIG. **8**C. The conductive ball **810** is housed in the conductive tube **860** between two springs **850**. The springs surround two conductive posts **870** and hold the conductive ball **810** away from the two conductive posts **870** while the motion detector **800** is standing still. Motion of the motion detector **800** will force the conductive ball **810** against one of the springs **850** which will compress and allow the conductive ball to touch one of the conductive posts **870** which completes a circuit with the conductive tube **860**. Each time a circuit is completed, the circuitry of the coupon implements a counter until the predetermined threshold is reached.

In one embodiment, the coupon comprises a dual-axis motion sensor with a ball in a cross-shaped channel. One example of this embodiment is depicted in FIG. **9**. In this embodiment, the motion sensor **900** comprises a conductive sphere **910** and rests inside a cross-shaped channel **920**. The shape of the channel fixes the potential movement of the ball **910** to two axes. At the end of each of the four channels there is an electronic contact **930** that closes a circuit whenever the ball **910** makes contact. The cross-shaped channel form and orientation to the device is defined by the orientation and the allowed movement.

In another embodiment, the coupon comprises a single-axis motion sensor. One example of this embodiment is depicted in FIG. **10**. The motion sensor **1000** is comprised of a single conductive flat spring **1010** in which one end is affixed to a circuit board **1020** or other conductive member and the other end contains a weight **1030** to amplify detected motion. Conductive stops **1040** are affixed to the circuit board **1020** and are equally spaced on either side of the flat spring **1010** and weights **1030**. Upon deflection, the conductive flat spring **1010** contacts conductive stops **1040**. When contact with the conductive stops **1040** occurs, a signal flows through the circuit board **1020** or other conductive member to the sensor then to the conductive stops and back through the circuit board. This signal is interpreted by control electronics indicating that motion has occurred. The conductive stops may be electrically joined or remain separate wherein the control electronics may interpret the signal received from the motion detector together or individually.

In one embodiment, the coupon comprises a dual-axis motion sensor comprised of a single conductive flat spring bent to form an angle of between 1 and 90 degrees. One example of this embodiment is depicted in FIG. **11**. Each end of the flat spring **1110** incorporates a weight **1120** to amplify detected motion. The bent end of the sensor **1110** is affixed to a circuit board **1130** or other conductive member. Conductive stops **1140** are affixed to the circuit board and are equally spaced on either side of the flat springs **1110** and weights **1120**. When contact with the conductive stops **1140** occurs, a signal flows through the circuit board **1130** or other conductive member to the sensor then to the conductive stops **1140** and back through the circuit board **1130**. This signal is interpreted by control electronics indicating that motion has occurred. Each of the four conductive stops **1140** may be electrically joined or remain separate. Therefore, the control electronics may interpret the signal received from the motion detector **1100** together or individually. In this embodiment, the motion detector may include an electronic circuit that incorporates algorithms capable of detecting and interpreting individual or joined signals from the motion sensor. The electronics can define orientation, number of deflections from each conductive stop and interpret the results. The resulting information is maintained in electrical storage or displayed on an enunciation device which may include a Liquid crystal display, Light emitting diode display or other means to store or communicate the resulting information to a user.

In one embodiment as depicted in FIG. **12**, the coupon comprises a motion sensor having a dual-axis or balanced pendulum motion detector **1200** composed of a pendulum **1210** which pivots at one end and contains a weight **1220** at the other, and which incorporates two balanced hair pin springs **1230** symmetrically located around the long axis of the pendulum **1210**. The hair pin springs **1230** balance the pendulum **1210** in a central location and allow deflection in two directions. Two contacts **1240** are located at either side of the pendulum weight **1220**. Deflection of the pendulum **1210** to either contact **1240** causes an electrical circuit to be completed between the pivot end of the pendulum **1210** through the weight **1220** to either contact **1240**. The contacts **1240** may be joined or separated. The pendulum **1210** may include electronic logic. This embodiment may further comprise an electronic circuit that incorporates algorithms capable of detecting individual or joined deflections and interpreting the inputs to correspond to the use, orientation and numeric quantity of deflections detected. The electronics interpret the information and send the results to a storage or enunciation device which may include a Liquid crystal display, Light emitting diode display or other means to store or communicate the resulting information to a user.

In one embodiment as depicted in FIG. **13**, the coupon comprises a motion detector **1300** comprising a spring wire **1310** with a dampening device motion detector. This embodiment includes a three-axis motion sensor **1300** in which a conductive spring **1310** wire is affixed to a selectively conductive mounting plate **1320** (such as a printed circuit board) and the other end incorporates a fixed weight **1330**. A predetermined length of the spring wire **1310** protrudes through a compressible material (such as open cell foam). The fixed weight end **1330** protrudes through a conductive hoop **1340**. The hoop **1340** is connected to the mounting plate **1320**. Upon deflection, the conductive spring wire **1310** deflects and contacts the conductive hoop **1340**. When contact with the conductive hoop **1340** occurs, a signal flows through the printed circuit **1320**. This signal is interpreted by control electronics indicating that motion has occurred. The conductive hoop may be electrically joined or remain separate wherein the control electronics may interpret the signal received from the motion detector. This embodiment may include electronic logic such as, for example, an electronic circuit that incorporates algorithms capable of detecting individual deflections and interpreting the inputs to correspond to the numeric quantity of deflections detected. The electronics

send the resulting information to a storage or display device such as, for example, a liquid crystal display, light-emitting diode display or other means to store or communicate the resulting information to a user.

In one embodiment, the coupon comprises a spring wire with dampening device motion detector and three-axis interpretation. This embodiment includes a three-axis motion sensor in which a conductive spring wire is affixed to a selectively conductive mounting plate (such as a printed circuit board) and the other end incorporates a fixed weight. A predetermined length of the spring wire protrudes through a compressible material (such as open cell foam). The fixed weight end is located between two individual contacts. A third contact is located on the selectively conductive mounting plate under the weight. Upon sensing motion, the spring wire is deflected and contacts one or more of the conductive contacts. An electrical signal flows through the selectively conductive mounting plate. This signal is interpreted by control electronics indicating that motion has occurred. The conductive stops may be electrically joined or remain separate wherein the control electronics may interpret the signal received from three contacts and the motion detector. The compressible material dampens oscillations from the spring wire. This motion detector may include an electronic circuit that incorporates algorithms capable of detecting individual deflections and interpreting the inputs which correspond to the use, orientation and numeric quantity of deflections detected. The electronics interpret the information and send the results to a storage or enunciation device which may include a Liquid crystal display, Light emitting diode display or other means to store or communicate the resulting information to a user.

In one embodiment, the coupon includes a motion detector that can detect 360 degrees of longitudinal motion and which is comprised of a platform with a single outer raised conductive ring, an inner conductive surface placed inside, but not contacting the raised conductive ring, a movable ball or "puck" is located inside the raised conductive ring, and a compressible porous member such as open cell foam, which fits around the movable ball or "puck" and which is compressed by the ball or "puck" as it is deflected by motion. The ball or "puck" is held in a central location by the compressible porous member. Upon sensing motion, the ball or "puck" is deflected and causes the porous member to compress in the direction the motion is detected and proportion to the energy contained in the motion. If the energy is sufficient, the porous member if fully compressed and the ball or puck makes contact through the porous member to the raised conductive ring. Making contact with the raised conductive ring caused an electrical circuit to be completed. This embodiment may include an electronic circuit that incorporates the algorithms capable of detecting deflections and interpreting the inputs to correspond to the use, orientation and numeric quantity of deflections detected. The electronics can define orientation, number of deflections from each conductive stop and interpret the results. The resulting information is maintained in electrical storage or displayed on a display device such as, for example a liquid crystal display, light-emitting diode display or other means to store or communicate the resulting information to a user.

In one embodiment as depicted in FIG. **14**, the coupon includes a motion sensor **1400** comprising separate or individual raised conductive ring members **1430** arranged equidistant from a center point and mounted on a platform **1410**, an inner conductive surface is located on the platform but not touching the raised conductive ring members **1430**, a movable ball **1420** or "puck" is located inside the individual raised

conductive ring members **1430**, and a compressible porous member which fits around the movable ball **1430** or "puck" and which is compressed by the ball **1430** or "puck" as it is deflected by motion. The ball **1430** or "puck" is held in a central location by the compressible porous member. Upon sensing motion, the ball **1430** or "puck" is deflected and causes the porous member to compress in the direction the motion is detected and proportion to the energy contained in the motion. If the energy is sufficient, the porous member if fully compressed and the ball **1430** or puck makes contact through the porous member to one or more of the individual raised conductive ring members **1430**. Making contact with one or more individual raised conductive ring members **1430** caused an electrical circuit to be completed. This motion sensor **1400** may include a electronic circuit that incorporates algorithms capable of detecting individual or joined deflections and interpreting the inputs to correspond to the use, orientation and numeric quantity of deflections detected. The electronics send the resulting information to a storage or enunciation device which may include a Liquid crystal display, Light emitting diode display or other means to store or communicate the resulting information to a user.

As depicted in FIGS. **15**A, **15**B, **15**C, **15**D, and **15**E, one embodiment of the present application comprises a coupon including a motion detector **1500** comprising a conductive element such as a ball **1510**, a dampening element such as a foam ring **1520**, and a conductive ring **1530** disposed on a substrate **1540**. The conductive ring **1530** surrounds an inner conductor **1550**. A cross-section of this motion detector **1500** is depicted in FIG. **15**C which shows the ball **1510** resting on the inner conductor **1550** and held apart from the conductive ring **1530** by the foam ring **1520**. As depicted in FIG. **15**D, motion of the motion detector will force the ball **1510** against the foam ring **1520**, deforming the foam ring **1520** and forming a circuit between the inner conductor **1550** and the conductive ring **1530**. In a further embodiment depicted in FIG. **15**E, the inner conductor **1550** may have channels, holes, or protuberances which inhibit the free movement of the ball **1510** and thus require additional motion to form a circuit.

A similar embodiment of a motion detector **1600** is depicted in FIG. **16** in which a conductive element such as a ball **1610** is disposed in a dampening element such as a foam ring **1630** which is placed inside a number of conductive posts **1650** on a substrate **1640**. An inner conductor **1660** is disposed in the middle of the motion detector **1600**. In this embodiment, the ball **1610** forms a circuit between the conductive posts **1650** and the inner conductor **1660** when the ball **1610** is subject to sufficient motion to deform the foam ring **1630** and allow the ball **1610** to contact the conductive posts **1650** while resting on the inner conductor **1660**.

FIG. **17** depicts another embodiment of a motion detector **1700** to be included with a coupon according to the present application. The motion detector **1700** comprises a conductive pin **1710** that may have a weight **1720** coupled to the end. The conductive pin **1710** may be surrounded by a dampening element such as a piece of foam **1730** which may be coupled to the substrate **1760** from which the conductive pin **1710** extends. The weight **1720** is surrounded by a conductive member **1740** and for a conductive plate **1750**. The movement of the motion detector **1700** will cause the weight **1720** to contact either the conductive member **1740** or the conductive plate **1750**, closing a circuit with the conductive pin **1710**.

A similar embodiment is depicted in FIG. **18**A. In this embodiment of a motion detector **1800**, a conductive pin **1810** with a weight **1830** extends from a substrate **1820**. The weight **1830** is surrounded by a plurality of conductive posts, **1840**, **1850** and positioned above a conductive plate **1860**. Motion

cause the conductive pin **1810** to contact either the posts **1840**, **1850** or the conductive plate **1860** which completes a circuit. A side view of this embodiment is depicted in FIG. **18**B.

One embodiment of a coupon is depicted in FIG. **19**. The coupon **1900** comprises a flexible band **1910**, a circuit **1920** which includes a motion detector, and a housing **1930** which holds the circuit **1920** to the flexible band. The flexible band **1910** may further comprise an adhesive strip on one or both ends in order to affix the coupon **1900** to a user. In some embodiments, the housing may be a pocket in the band and not a separate component. In another embodiment, the housing may also be coupled to the sensor and then affixed to the band.

In one embodiment, the coupon comprises a motion detector comprised of individual contacts arranged on a sliding surface and which are spaced equidistant from a center point and which alternate in conductivity. A ball or puck is contained inside the contacts and which upon being tilted, slides against the contacts and creates a circuit. The sensor can detect tilts at 45 degree quadrants.

In one embodiment, a coupon comprises a series of light emitting diodes which provide signals to a user. One embodiment of a method of measuring physical activity and conserving battery power of a coupon is depicted in FIG. **21**.

Intelligence may be built into a coupon such that the coupon does not begin to measure physical activity until a predetermined time has passed. Thus, the coupon is not activated until a predetermined time. This may be advantageous when a number of coupons are presented to a user, such as in a physical therapy application where the user is given a number of coupons that must be activated at different times. The activation of certain coupons at different times will prevent the user from wearing all of the coupons at the same time.

In one embodiment, the coupon may also serve as a gift card. The gift card would be purchased for a fixed dollar amount. Typical of traditional gift cards, the gift card may be redeemed for the purchased value or if the consumer chooses to engage in physical activity for a predetermined level or amount of time, the gift card may increase in value. Suppose one purchases a gift card from a book store for $20 and gifts the card to someone. This individual may choose to use the gift card to purchase merchandise for the value of $20 or may choose to engage in physical activity to increase the value of the gift card (perhaps the gift card will increase in value from $20 to $25).

In one embodiment, the coupon comprises a ring motion detector with equidistant non-alternating contacts. The motion detector is comprised of individual contacts arranged on a sliding surface and which are spaced equidistant from a center point and which do not alternate in conductivity (i.e. ++, −−). A ball or puck is contained inside the contacts and which upon being tilted, slides against the contacts and creates a circuit. The sensor can detect tilts at 90 degree quadrants.

In one embodiment, the coupon comprises a ring motion detector with equidistant pairs of alternating contacts. The motion detector is comprised of pairs of contacts arranged on a sliding surface and which are spaced equidistant from a center point and the contact of which alternate in conductivity. A ball or puck is contained inside the contacts and which upon being tilted, slides against the contacts and creates a circuit. The sensor can detect tilts at 45 degree quadrants. Space between alternating contacts changes speed and transition of the ball or puck from one set of contacts to the other.

In one embodiment, the coupon comprises a motion detector comprised of pairs of contacts arranged on a sliding surface and which are spaced equidistant from a center point and the contact of which do not alternate in conductivity. A ball or puck is contained inside the contacts and which upon being tilted, slides against the contacts and creates a circuit. The sensor can detect tilts at 90 degree quadrants.

In either of the ring designs described above, a hole may exist in the center of the ring surface (i.e. printed circuit board). This will allow the ball or puck to remain idle or in a stationary position during a time when the motion detector should not be registering hits (i.e. during transportation).

In another embodiment, the motion detector is comprised of pairs of electrical contacts arranged around the circumference of a sliding surface. A plurality of holes or protuberances are incorporated into the sliding surface. A conductive object such as, for example, a sliding puck or rolling ball, touches the electrical contacts upon tilting of the motion detector and creates electrical contact between the contacts. The holes or protuberances in the sliding surface alter the friction between the conductive object and the surface thereby adjusting the reaction of the conductive ball or puck to tilting. When the conductive object contacts one or more of the electrical contacts, a circuit is formed between the contacts and the contact is recorded by a device.

A final and third methodology for monitoring the user's motion is achieved using electrical technology, as shown in FIG. **5**. In accordance with this third method electrical energy is captured by moving a magnet **515** around or through a coiled wire. A change in the magnetic field includes an electromotive force or voltage in inductor L**1**. Four diodes denoted as D**1** represent a bridge rectifier to convert the AC voltage generated in inductor L**1** to DC voltage for storage by a capacitor C**1**. Similar to that described above with respect to the other methodologies, the electrical methodology also disregards physical activity or movement by the user which is inconsequential or insignificant (falls below a predetermined threshold level). To achieve this result, a triggering signal is transmitted to power ON a chemical or electrical circuit **505** only when the stored voltage in capacitor C**1** exceeds a predetermined threshold voltage level of physical activity or movement. In the ON state, the voltage is used to power an electronic circuit that electronically records the level of physical activity in memory **510** and change the pH of a compound of a chemical indicator thereby producing a color to signify to the user that the kinetic coupon has been validated or activated and is now redeemable.

It is to be noted that each of the methodologies described above may be used independently or in any combination thereof.

Many additional features may be added to the inventive kinetic coupon. A timing clock may be employed to ensure that the kinetic coupon is validated and/or redeemed after being validated prior to expiration of a predetermined redemption period of time. Upon the expiration of the predetermined redemption period of time, the kinetic coupon if not yet validated will no longer be activatable and, if already validated, will become inactive or perhaps indicate on the display that it is no longer redeemable.

The kinetic coupon may be reusable whereby after validation and redemption the components may be reset and used again. Otherwise, it is also contemplated and within the intended scope of the application for all or some portion of the kinetic coupon to be disposable. One factor in this determination is the overall cost associated with the components of the kinetic coupon itself.

As previously noted, the kinetic coupon may be designed or customized, as desired, to promote the specific corporation or sponsor. For example, the name, trademark, logo, or other

indicia of the corporation or sponsor may be displayed on the strap or other portion of the coupon including in the display itself. In this regard, the kinetic coupon may be used as yet another advertising tool for promotion of a corporate or sponsor's name, brand, and/or product/service. Additional companies or advertisers may be added to the kinetic coupon.

FIG. **6** is an exemplary flow chart of the user of the kinetic coupon in accordance with the present application. In step **600** in inactive coupon is dispensed to the user. Initially, the kinetic coupon is not activated and this not redeemable for any type of reward or incentive. However, the indicia may display instructions that invite the user to participate in physical activity or movement while in possession of the inactive kinetic coupon in step **605**. A determination is made in step **610** whether the user's participation in physical activity exceeds a stored predetermined threshold, e.g., a predetermined amount of physical activity and/or a predetermined period of time. After the user has participated in physical activity for at least the predetermined threshold then in step **615** the kinetic coupon is validated and signifies to the user that it is now able to be redeemed.

In one embodiment, the coupon comprises a system for encouraging physical activity in children. In this embodiment, a child is issued a coupon from a source which may be the child's parents, the child's school, or an entity such as a restaurant or other vendor. The parent or guardian of the child may set up an account such as, for example, a bank account or a points account for the child on a web site. When the child engages in physical activity that exceed the predetermined threshold set by the coupon, the coupon will success to the child with an indicator such as a code. The code may then be entered into the web site by the parent or guardian or by the child to redeem the coupon for a predetermined amount of points or currency. In the embodiment where an online bank account is set up for the child, the coupon may be redeemed for currency which is deposited into the child's account.

In one embodiment, a coupon according to the present application comprises a self-contained game that monitors the physical activity of a user and provides feedback to the user based on the level of physical activity of the user. The game will react to the physical activity of the user and issue points or rewards to the user based on the level of physical activity recorded by the coupon.

One example of this embodiment is a virtual pet that is displayed on a display such as a liquid crystal display on the coupon. The virtual pet will appear as healthy when the coupon has detected a predetermined amount of physical activity from the user and the virtual pet may appear ill if the coupon detects an amount of physical activity below a threshold level. The pet may also grow and become stronger upon detection of a number of different thresholds of physical activity. In a further embodiment, the coupon monitors only recent physical activity from a predetermined time in the past until the present. This ensure that the user regularly engages in physical activity to maintain the health of the virtual pet.

In one embodiment, the coupon interacts with an online game which responds to the amount of physical activity detected by the coupon. Such a game may reward the user upon the detection of certain threshold levels of physical activities from the coupon.

In one embodiment, a coupon according to the present invention may be issued as a label on food or beverage products, a peel-off addition to packaging of goods, or a promotional label that may be sold in office supply stores and printed with a company's promotional logo.

In one embodiment a device including a coupon has a removable component that alerts the user when a predetermined level of physical activity has been reached. The removable component has a display or other visual indication as described herein to inform the user how much physical activity has been achieved while wearing the device and/or whether the predetermined level of physical activity has been reached. The removable component may fit into a device such as a wearable bracelet, anklet, or other device as described herein. The removable component records the amount of physical activity detected by a motion sensor in the removable component.

The removable component may be added to a second device such as, for example, a toy that is able to detect the amount of physical activity recorded by the removable component or some other signal from the removable component corresponding to the amount and/or level of physical activity recorded. The second device reacts to the amount and/or level of physical activity recorded by the removable component in one or more ways such as, for example, activating the features of the second device for a predetermined period of time or unlocking special features upon detection of a certain amount and/or level of physical activity recorded by the removable component.

One example of a device with a removable component that may be used with a second device is a bracelet with a removable component configured to record an amount of physical activity undertaken by the user while wearing the bracelet that is detected by the bracelet. The user may remove the removable component from the bracelet and insert the removable component into a video game console, which will allow the user to play video games only if a predetermined amount and/or level of physical activity has been recorded by the removable component. The video game console may provide bonuses to a user such as, for example, additional playing time or additional available games, if a certain amount and/or level of physical activity has been recorded. In one embodiment, the video game console will allow playing time commensurate with the time of physical activity recorded by the removable component.

One example of a removable component is depicted in FIGS. **22**, **23**, and **24**. A first device **2200** includes a wrist strap **2210** to be worn by a user. The first device **2200** further includes a motion sensor and a removable component **2220** for recording the physical activity of a user wearing the first device **2200** as detected by the motion sensor. The removable component further includes a display **2340** to alert the user when a predetermined amount and/or level of physical activity has been recorded. The removable component may include electrical contacts **2230** to communicate with the wrist strap **2210**.

The removable component **2320** is depicted in FIG. **23** as being inserted into a base station **2350**. The base station **2350** may serve to retrieve information from the removable component **2320** and transmit the information to a second device, such as the video game console as described above. The base station **2350** may also include a Universal Serial Bus adapter or other connector or coupling device so that the removable component **2320** may be coupled to a computer such as, for example, a personal computer. Information from the removable component **2320** may be transmitted to the personal computer if a user wishes to examine the precise levels of physical activity recorded by the removable component **2320** or if a user wishes to record all physical activity over time that has been recorded by the removable component **2320**. The removable component **2320** may also be used to enable certain applications on the personal computer such as, for example, computer games. The removable component **2320** may also enable particular features of a application such as,

for example, points in a particular game, different levels in a game, special skills in a game, or online currency redeemable for goods or services.

FIG. **24** depicts the removable component **2320** being inserted into a toy car **2460**. In this embodiment, the toy car **2460** functions based on the amount and/or level of physical activity recorded by the removable component **2320**. The car **2460** may, for example, only function for a specific time based on the amount and/or level of physical activity recorded by the removable component **2320**. The car **2460** may also make special features available to a user based on the amount and/or level of physical activity recorded by the removable component **2320** such as super speed or stunt driving.

In one embodiment, the removable component includes a transmitter such as a RFID transmitter that communicates with devices such as, for example, toys or computer games. The transmitter will send a signal to such devices when a predetermined level of physical activity has been recorded by the removable component and the devices may activate or function in specific ways based on the signals. This obviates the need to insert the removable component into a second device for the second device to function in a specific way based on the amount and/or level of physical activity detected or recorded by the removable component. The transmitter may send signals to a second devices for a predetermined time based on the amount and/or level of physical activity recorded by the removable component or may send signals only while the removable component is presently detecting physical activity. When equipped with a transmitter, the removable component needs not be removable but instead may communicate with the second devices via radio frequency, infrared, or some other communications method or protocol.

The removable component may also accumulate points for the amount of physical activity recorded and these points may be uploaded to a web site through a computer. The web site may provide a variety of bonuses based on the amount of points accumulated by a user.

In one embodiment, a coupon may include intelligent logic that detects not only physical activity, but also levels of physical activity and types of physical activity. The coupon will discern between activities such as running, walking, and jumping jacks and record the level of a user's participation in each such activity. The coupon may require a user to participate in a predetermined level of a plurality of activities before the coupon is redeemable. The coupon may also include a plurality of indicators or displays each corresponding to one of a plurality of physical activities to alert the user when a predetermined threshold has been reached for each of the plurality of physical activities.

In an embodiment wherein a coupon detects a plurality of types of physical activity, the coupon may include a removable component which records the different types and levels of physical activity detected by the coupon. The removable component may then interact with a device such as, for example, a toy which will react to the amount and the types of physical activity recorded in the removable component by providing bonuses or special features based on the level and the type of physical activity the user has achieved. For example, the device may be a toy robot which includes a space for insertion of the removable component. If the removable component has recorded a predetermined threshold of jumping jacks, the toy robot may talk. If the removable component has recorded a predetermined threshold of running, the toy robot may walk. In this way, a device such as a toy will respond to the various physical activities achieved by a user. As described above, the removable coupon need not be removable.

Thus, while there have been shown, described, and pointed out fundamental novel features of the application as applied to a preferred embodiment thereof, it will be understood that various omissions, substitutions, and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit and scope of the application. For example, it is expressly intended that all combinations of those elements and/or steps that perform substantially the same function, in substantially the same way, to achieve substantially the same results be within the score of the application. Substitutions of elements from one described embodiment to another are also fully intended and contemplated. It is also to be understood that the drawings are not necessarily drawn to scale, but that they are merely conceptual in nature. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

Every issued patent, pending patent application, publication, journal article, book, or any other reference cited herein is each incorporated by reference in their entirety.

What is claimed is:

1. An apparatus for encouraging physical activity of a user, the apparatus comprising:

a wearable device comprising a removable component having one or more motion sensors that monitor physical activity of the user based on a motion of the removable component,

wherein the removable component includes a computer memory,

wherein the removable component includes circuitry configured to disregard physical activity monitored by the one or more motion sensors that is less than a value of a threshold amount of physical activity set in the computer memory, the circuitry further configured to record in the computer memory physical activity monitored by the one or more motion sensors that is greater than the value of the threshold amount of physical activity set in the computer memory,

wherein the removable component includes a visual indicator that indicates an amount of the monitored physical activity recorded in the memory; and

wherein the removable component wirelessly communicates information related to the monitored physical activity recorded in the memory to at least one secondary device.

2. The apparatus of claim **1**, wherein the at least one secondary device comprises a mobile device, a computer, a gaming console, or a toy.

3. The apparatus of claim **1**, wherein the wearable device further comprises a wearable housing that is securable to a body of the user, and from which the removable component is detached.

4. The apparatus of claim **3**, wherein the wearable housing comprises a bracelet, anklet, necklace, headband, hat, scarf, glove, clothing, footwear, pin, clip, eyewear, belt, or neckwear.

5. The apparatus of claim **3**, wherein the removable component is configured to fit into a second wearable housing.

6. The apparatus of claim **1**, wherein the removable component wirelessly communicates information related to the monitored physical activity to the at least one secondary device via a wireless transmitter.

7. The apparatus of claim **1**, wherein the computer memory is configured to store information related to multiple different types of activity represented in the monitored physical activity.

8. The apparatus of claim **1**, wherein the visual indicator comprises a light-emitting diode (LED).

9. The apparatus of claim **1**, wherein the one or more motion sensors are configured to detect one or more activity types comprising the monitored physical activity.

10. The apparatus of claim **9**, wherein the one or more activity types include running and walking.

11. The apparatus of claim **9**, wherein the visual indicator comprises a plurality of indicators, each of which corresponds to a different activity type.

12. The apparatus of claim **9**, wherein the at least one secondary device provides one or more rewards based on the information related to the monitored physical activity.

13. An apparatus, comprising:

a wearable device including a removable component having one or more motion sensors that monitor physical activity of a user wearing the wearable device based on a motion of the removable component,

wherein the removable component includes a memory configured to store a value for a threshold amount of movement, the threshold amount of movement indicating either a number of steps, or a number of stairs, or a combined number of steps and stairs,

wherein the removable component includes a visual indicator that indicates an amount of the monitored physical activity, the visual indicator including a series of light emitting diodes arranged in a line and spatially separated from each other, the series of light emitting diodes configured to turn on in a progression from one end of the line toward another end of the line, an amount of the progression indicating a current progress of an amount of physical activity monitored by the one or more motion sensors toward the threshold amount of movement as recorded in the memory, and

wherein the removable component includes a transmitter configured to wirelessly communicate information related to the monitored physical activity to at least one secondary device.

14. The apparatus as recited in claim **13**, wherein the series of light emitting diodes includes at least three light emitting diodes.

15. The apparatus as recited in claim **13**, wherein the series of light emitting diodes includes five light emitting diodes.

16. The apparatus as recited in claim **13**, further comprising:

an electrical contact provided at an exterior surface of the removable component.

17. The apparatus as recited in claim **16**, wherein the electrical contact is configured to connect with an electrical contact of a coupling device to enable charging of the removable component through the coupling device.

18. The apparatus as recited in claim **13**, wherein the transmitter is configured to generate and transmit radio frequency signals in accordance with a communication protocol.

19. The apparatus as recited in claim **13**, wherein the at least one secondary device is one or more of a computer, a game, a toy, a game controller, a computer interface device, a cell phone, a mobile data communication device, and a microprocessor.

20. The apparatus as recited in claim **13**, wherein the wearable device includes a wristband having a pocket configured to receive and hold the removable component.

21. The apparatus as recited in claim **13**, wherein the wristband includes a clasp.

22. The apparatus as recited in claim **13**, wherein the light emitting diodes of the series of light emitting diodes are the only light emitting components of the visual indicator.

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